Attracting New Coating Businesses by Offering Flexible Manufacturing

By
Maribel Sierra

B.S. Industrial Engineering Northeastern University 1997

Submitted to the Sloan School of Management and
Mechanical Engineering in partial fulfillment of the
Requirements for the degrees of

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Abstract

As many other companies, Polaroid's coating plants are feeling the pressure to reduce costs. To achieve this goal, Polaroid is maximizing the use of existing equipment and reducing under-utilization costs by increasing production volumes. However, Polaroid's internal production is not enough to achieve these objectives because of current production levels and new products have not yet fully utilized the available capacity.

Polaroid's strategy is to focus on outside contracts by offering its expertise and equipment capabilities. This alternative brings an interesting question: How can Polaroid attract businesses to fully utilize its coating lines and hence reduce costs? High quality and high technical expertise are two characteristics that make Polaroid attractive to potential customers. However, Polaroid must also increase its manufacturing flexibility and fast response; two competencies that at the present time customers are demanding.

Reduction in changeover times allows capturing the competitive advantage that increased flexibility offers. When Polaroid can change its equipment over in minutes instead of hours, the result is a capacity increase, inventory reduction, quality improvement, cost optimization and flexibility to meet world competition.

The analysis of the changeover operation was done to three coating facilities (N2, W5, and NB6). The project goal was to improve the coating operation efficiency of these sites by minimizing changeover time 15 to 45%. A systems approach of the problem was used to include all aspects involved during a changeover; from training, to machine design, to organizational structures were identified.

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Assistant Professor David S. Cochran, Department of Mechanical Engineering, MIT
Professor Roy E. Welsch, Sloan School of Management, MIT
Tom DeNoto, Polaroid Corporation

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TABLE OF CONTENTS

TABLE OF FIGURES

1. Introduction

As many other companies, Polaroid's coating plants are feeling the pressure to reduce costs. To achieve this goal, Polaroid is maximizing the use of existing equipment and reducing under-utilization costs by increasing production volumes. However, Polaroid's internal production is not enough to achieve these objectives because of current production levels and new products have not yet fully utilized the available capacity.

Polaroid's strategy is to focus on outside contracts by offering its expertise and equipment capabilities. This alternative brings an interesting question: How can Polaroid attract businesses to fully utilize its coating lines and hence reduce costs? High quality and high technical expertise are two characteristics that make Polaroid attractive to potential customers. However, Polaroid must also increase its manufacturing flexibility and fast response; two competencies that at the present time customers are demanding.

Setup capability is a reflection of overall manufacturing competency [1]. If Polaroid can complete a changeover in minutes rather than hours, the results are a capacity increase, inventory reduction, quality improvement, cost optimization and flexibility to meet world competition.

This study intends to aid Polaroid's Coating Division to focus on this strategy. The Coating Division is aware of the need to make changeover more efficient. However, it will represent a mayor shift from the way manufacturing lines are currently ran. Changeovers are done with no rush since manufacturing lines are underutilized and little pressure exists from customers (mostly internal) to deliver products quickly.

1.1. Specifics of the Problem

The goal of this study is to explore how Polaroid's Coating Division can reduce its changeover time making the coating operation more efficient; that is, reduce downtime, waste and improve standardization of procedures, safety conditions, flexibility and documentation. The study will describe current operations at three of Polaroid's coating facilities (Norwood 2 (N2), Waltham 5 (W5), and New Bedford 6 (NB6)), identify areas where changeover time can be improved, recommend changes, and develop an assessment model for future reference.

1.2. Objectives

This six-month study had two primary objectives from which specific goals were identified. They are:
Primary Objectives:

- To explore how coating lines can be more flexible by reducing changeover times
- To provide a systematic and holistic analysis of how the coating operation can be more efficient

Specific Aims:

- To understand current operations at Polaroid's coating facilities
- To identify areas where changeover time can be improved
- To recommend changes
- To advocate why such changes should be implemented
- To offer a flexible manufacturing assessment model for future reference
- To identify best practices by conducting internal and external benchmarking

1.3. Methodology

Using a systematic approach, a research methodology was developed to analyze the changeover process at N2, W5 and NB6. The same methodology was applied to all 3 coating sites. The study was conducted from June 2000 to December 2000. Observations and data collection at each site lasted 4-5 weeks.

Data were collected according to Single Minute Exchange Die (SMED) approach. The SMED is a validated approach used by the auto industry to reduce changeover time. Its concept is applicable to the coating industry since it focuses on eliminating non-value-added time and reducing the number of tasks that occur during the changeover and not on specifics of a particular industry [2]. Refer to Chapter 3 for a more detailed explanation of SMED. The steps for SMED include:

1. Interviews, observations, and videotaping the changeover process to understand its steps
2. Identify which activities of the changeover process are internal or external
3. Eliminate adjustments where possible
4. Develop a standardized changeover procedure

By using the above methodology the following issues were identified:

- Internal best practices that can be shared across sites

- Steps that can be completed while the machine is running (external)
- Changeover bottleneck at each site
- Wasted motions and time (non-value added)
- Areas of poor machine design and accessibility
- Schedule problems that increase changeover time
- Best organizational structure to complete a changeover
- Difficult ergonomic or working conditions
- Standard changeover procedure
- External benchmarking to understand how the industry is addressing the changeover challenges

To facilitate the analysis, the above issues were grouped as follows:

I. Work methodology practices:

- Deficient working conditions that require low cost improvements
- Difficult working conditions due to work methodologies
- Unstable production schedule that extend changeover time

II. Machine Design:

- Wasted motion and complex designs
- Poor machine accessibility
- Difficult working conditions due to machine design

III. Organizational capabilities:

- Limited cross-training
- Undefined changeover crew structure
- Poor motivation to change

IV. Communication:

- Inefficient documentation of procedures and checklists
- Poor integration of different participants involved in a changeover

The following questions were asked at each step of the coating process:

- Where is the bottleneck operation? Is it dispensing the chemicals, exchanging parts of the machine, running the new parameters or cleaning the machine?

- What are the external steps that can be done while the machine is running?
- How does poor machine design affect the changeover time?
- Are there any adjustments or non-value adding steps that can be eliminated?
- Are working conditions affecting the changeover?
- What type of organizational structure can facilitate a rapid changeover operation?

The final step of the methodology was to identify best practices for efficient, quick changeover procedures inside and outside of Polaroid. Five different coating industries were selected to perform the external benchmarking. To conduct the external benchmarking, a standard questionnaire was used to gather information. The data that were collected with the questionnaire included labor structure, labor morale, training, scheduling and production requirements, equipment configuration, and operations challenges (see Appendix B). Using a system analysis, that is analyzing all the things that are related to one another, helped develop an understanding of the unique changeover system. Some elements of the system included: the analysis of the changeover processes, the comparison of these processes within Polaroid and the other industries, and the identification of best practices.

1.4. Glossary of Terms

- *Applicator:* It is a device used to deposit a coating layer on a web. Different applicator techniques are used at Polaroid (slot, cascade, gravure, reverse, and forward roll). Applicators have the same width as the web.
- *Chemical Mix Area:* Closely involved during the changeover process, the Chemical Mix area prepares and dispenses the fluids for the coating line.
- *Coating:* It is the process by which a gas originally at the substrate surface is replaced with a liquid film. Typically, the preferred films are continuous and uniform, as well as maintainable until solidified, dried or transferred.
- *Drier:* (Synonym: oven) It is a device used during the coating process to dry a coated web.
- *Flexibility*: The ability to respond quickly to customer demands, which includes mobility to change from one product to another, attitudes to change quickly, and organizational agility to change.
- *Kaizen event:* A one-week activity where a cross-functional team focuses on improving one area following the 5S principles of Kaizen. The cross-functional team implements the recommendations made.
- *Leader:* Substitute material run through the coating machine to test new parameters for the next product run. Running leader completes the changeover process.

- *Module:* It is a station where a web is coated. A module can be fixed or exchangeable.
- *Setup:* see changeover.
- *SMED:* Single Minute Exchange Die. Methodology used in the auto industry to minimize changeover time.
- *Web:* (Synonyms: substrate, base material) It is the material to be coated - paper, polyester, cloth, etc.- as one-piece roll and which is threaded throughput the coating line.
- *Changeover*: (Synonym: setup) For the purpose of this study, changeover was agreed to be defined as the time the last product is produced to the time the first good product of another product family is produced [3]. Changeover includes shutting down the machinery, changing the modules and setting new parameters (see Figure 1). Within setting the new parameters, inspection is done to guarantee quality. Polaroid's employees had different definitions for changeover. Some employees define changeover as the steps required to change the modules for a new product. For others, it implies shutting down the machinery. A final group of workers include setting the new parameters.

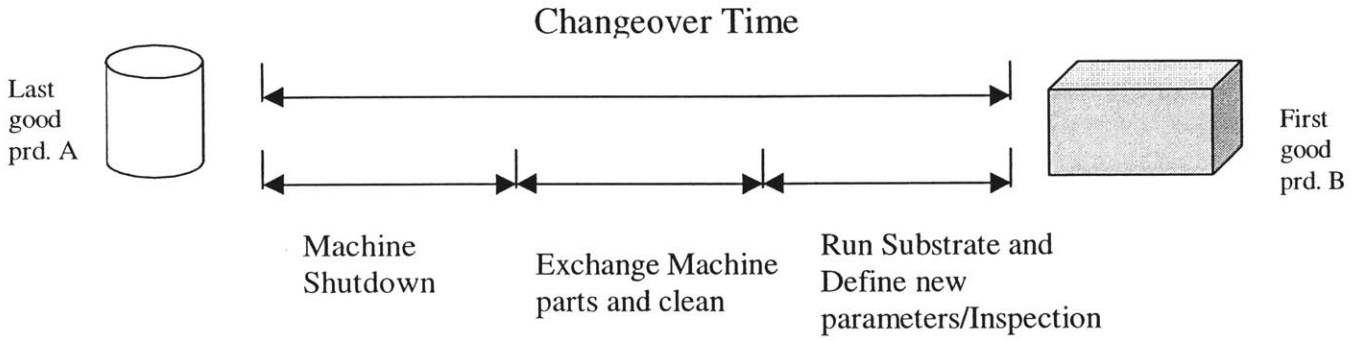


FIGURE 1 Changeover Time definition

1.5. Thesis Organization

Chapter 2 provides background information on Polaroid's coating process. It also highlights the differences and characteristics of each of the three coating plants.

Chapter 3 summarizes the best practices identified through literature review. This chapter also discusses the current changeover practices at each coating plant and for the companies benchmarked.

Chapter 4 presents the analysis and recommendations to improve the changeover process and to run a more flexible manufacturing coating line. The recommendations can reduce changeover time by 15-50%.

Chapter 5 discusses ways to improve the methodology used during this study. It also introduces a diagnostic model for future assessment of how flexible any manufacturing line is.

2. Background

2.1. Polaroid Corporation

Polaroid Corporation, headquartered in Cambridge, Massachusetts, was founded in 1937 by Dr. Edwin Land to develop light polarization materials and technology. In 1944, Dr. Land first discovered the one-step photographic system that has since become synonymous with the company name. The first version of this product was sold in Boston in 1948. Today, the instant photographic system continues to be Polaroid's mainstay product.

The company is the worldwide leader in instant imaging with annual sales of approximately $2 billion. It supplies instant photographic cameras and films; digital imaging hardware, software and media; secure identification systems; and printing media to markets worldwide.

Polaroid's financial health has recently been affected by at least two market conditions. On the one hand, the company had little financial success developing alternative projects such as medical imaging, graphic arts pre press proofing, and holographic technology. In addition, the instant film business suffered sale declines primarily due to increasing competition in the digital photography. As a result, the company's performance and cash position suffered considerably over the past few years. These factors have forced the company to refocus its core business and to introduce new products to spur growth, particularly products that are focused on the digital world yet integrated with the traditional instant photography.

As Gary T. DiCamillo, Chairman and Chief Executive Officer of Polaroid Corporation, said during the announcement of year 2000 – 4th quarter expectations [4]:

> "...But the change in trade buying patterns we saw at the end of the third quarter is continuing in Q4. While our new products are doing well, it appears that slowing economic growth and more conservative stocking policies are negatively impacting shipments of our traditional film lines. Additionally, we are forecasting a more conservative economic outlook for 2001 and, therefore, are planning a number of actions to strengthen our balance sheet and cash flow."

2.2. Polaroid's products

2.2.1. Polaroid's Instant Film:

Instant Film represents the high margin product for Polaroid. The company has four coating facilities manufacturing three different types of instant film: Peel-apart, Integral and Pocket. Each shares the principle technology of instant film, but with different functionality. Peel-apart film is marketed to professional photographers and businesses. Peel-apart film requires careful handling and experience to achieve best results, and contrary to Integral film, after manually being removed from the camera, it must be manually separated 60 seconds after exposure. The Integral film is a fully integrated package that is ejected from the camera and is developed in the environment after exposure. The market niche for the Integral film is the average customer. Introduced in 1999 as the I-Zone camera, Pocket Film targets teenagers and children; it is similar to the integral film, but in a smaller format.

When an Instant film is exposed, the image appears first on a negative. As reagents develop the image, the final image (print) appears on the positive. Although its use is simple, the process of manufacturing Instant film is complex. For this reason and to take advantage of economics of scale, Polaroid manufactures the main chemical components in a vertically integrated fashion.

2.2.1.1. *Film Components:* Instant films have three basic components: a negative, a positive and reagents. For Integral films, the 3 components are, for example, part of an "integral" package. The reagent is sealed into pods that burst when the film is ejected from the camera, developing the negative as it spreads. All components are currently manufactured at Polaroid except the base material, which is bought from an outside vendor.

2.2.2. Polaroid's Integrated Camera:

Polaroid's photographic system does not have a modular design that allows films and cameras from different sources to be used interchangeably. A strong interdependency between film and camera permits a high quality image. Although chemicals are produced at Polaroid, some critical hardware components for the camera, such as the roller mechanism that spreads the reagent, are generally outsourced.

The most important business characteristic of hardware is in the film "burn" or usage rate; consequently, hardware is developed to sell film. Nevertheless, Polaroid has opened markets in digital cameras, for the past couple of years.

2.3. Coating Process

"The coating process has been described as the application of a covering, finish, or protective layer on one or two sides of a substrate [5]." Contrary to its definition, coating is a complex process that involves multiple steps in a continuous flow operation.

"The coating machine can be divided into three main elements: the coating head (applicator), the coating solidification system (dryers, chill rollers), and the web or sheet tension and transport system [6]." Coating machines can be as simple as one applicator and one drier or as complex as multiple applicators (each with different coating techniques) and several dryers (each with different temperatures or drying techniques).

A coating head can deposit a single layer or multiple layers of coating material onto a substrate. The following are some techniques to deposit the coating fluid onto the substrate [7]:

1. Slot Coating: The thickness of the coated liquid layer is set by a prescribed flow rate fed into the coating die and is independent of the process variables, making the ideal method for high precision coating.
    - Advantages: predetermined coating thickness, coating uniformity, fast coating speed and simultaneous multi-layered coating
    - Disadvantages: bounded by low flow and high flow limit, air entrapped in the fluid, and limited solution properties.
2. Cascade/Slide Coating: Rectangular plates separated by flow channels are stacked allowing a fluid to exit through slots and to flow down an inclined plane.
    - Advantages: Several layers can be deposited with one application
    - Disadvantages: Fluid coverage is poor
3. Gravure Coating: A fluid is metered using a patterned roll, which can be chrome plated or ceramic. The fluid is forced into patterned cells by a doctor blade, which then removes the excess fluid. Finally, the fluid is transferred from the cells onto a substrate.
    - Advantages: Precise control of coverage and can be used for low viscosity fluids

- Disadvantages: Lack of versatility and requires more changeover time to exchange the rolls

4. Forward Roll Coating: Rolls rotate in the same direction as the substrate; at least one of the rolls is rubber covered. This process has the capability of coating one side at a time or both sides simultaneously.
   - Advantages: Used for low coverage, low viscosity fluids, and rough substrates
   - Disadvantages: Not a metered coating (dependent on fluid characteristics) and susceptible to ribbing (non-uniform coating)
5. Reverse Roll Coating: Rolls rotate in opposite direction to each other. The coating coverage is regulated primarily by gap setting and by roll speed ratio.
   - Advantages: Applicable for smooth coating, high concentration fluids, wide range of viscosity, and rough substrate
   - Disadvantages: Not a metered coating and susceptible to ribbing

To convert a coating material from liquid to solid, the web has to pass through a solidification system (oven), which may vary in number and types depending on the base material, the coating process, and the coating material. The web is finally transported to the slitting room where it is cut into its required width.

2.4. Polaroid's Coating Plants

This section describes Polaroid's coating plants, including their products, their performance metrics, and their working environment (see Table 1).

2.4.1. N2 Coating Plant:

Located in Norwood, this site manufactures mainly two products for the business and professional photography markets: Printcoat and Coaterless. Although N2 is capable of producing other products such as instant 35 mm-film Cartridges, Printed TM, and Deli Strip, production volumes are low compared to the first two products.

2.4.1.1. Product Families

- Printcoat: This product family includes the Peel-apart instant film and represents the original products invented by Dr. Land. Printcoat is known for detailed black and white prints, gradual tonal range, and excellent highlight and shadow detail. Characteristics that are sought by highly specialized customers.

Raw materials used for Printcoat are chemicals and base material. Chemicals are provided from the in-site Chemical Mix area in either bulk or portable vessel quantities. They have tight expiration times, which can create delays during the changeover (see Chapter 3). To avoid expiration times, fluids are processed only in batches. Base material, on the other hand, is currently purchased from an outside vendor.

The Printcoat process flow has multiple complex steps (see Figure 2). First, the base material goes through a coater to receive four different coatings, each using a different coating procedure, then inspected and stored in a warehouse. Next, the completed roll has to run through the coater again to be equilibrated, which is done to avoid contamination in some products. The roll goes through the slitter to be cut into specific widths. Finally it is shipped to the customer.

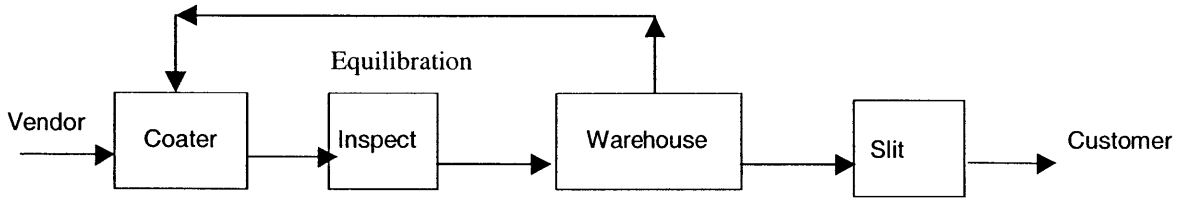


FIGURE 2: Printcoat process flow

The Printcoat process encounters several challenges throughout its entire production of which the most significant is the complexity and uncertainty of the process. As a consequence, it can cause important changes to production schedules that in turn affects the changeover schedule. It also creates stress and frustration among workers.

- Coaterless: A form of Peel-apart instant film, it represents the highest volume of production for N2. Coaterless possesses unique qualities and characteristics sought by professional photographers.

Although the Printcoat and Coaterless processes use the internal Chemical Mix group to dispense the chemicals, the two processes have several differences. For instance, chemicals for the Coaterless process can be prepared in larger batches since they do not have tight expiration time as fluids used in Printcoat. The Coaterless process is also more stable than the Printcoat causing fewer problems to the production system. Moreover, Coaterless has only three coating procedures and does not require equilibration. As a consequence, changeovers are more predictable for the Coaterless than for the Printcoat.

2.4.1.2. *Performance Metrics*

All coating facilities track two important metrics: yield and utilization. On the one hand, yield is tracked under a ratio called First Pass Yield (FPY), which represents the percentage of good product resulting after the web has been coated, dispositioned, slitted, and inspected. During last year, N2's FPY has gradually improved for Coaterless, but has declined for Printcoat. Overall, N2 has lower FPY compared to W5.

On the other hand, utilization represents the percentage of time that the coater is used to produce goods. Excluding July 1998's shutdown period, utilization dropped by more than 8% from 1998 to YTD (6/00), reinforcing the need to attract new businesses to N2 to use underutilized equipment.

2.4.1.3. *Working Environment*

Several characteristics were observed at each site to understand its culture, politics, structure, and employees' attributes; all of which have direct effect on employee's performance during a changeover.

- Expertise Level: Although N2 has a highly technical exempt staff, which is well suited for the complex Printcoat process, the non-exempt employees have a diverse expertise level. As a consequence, few senior operators cover for a large majority of employees with fewer skills.

- Training: Because the formal training activities is minimum, job training is done peer to peer. A reimbursement program exists for employees to pursue continuous education and training, but little incentive exists to take advantage of the program. In

addition, cross training seldom occurs on the floor. Nevertheless, after this study was completed, a new pay plan that rewarded cross training and two formal training programs were adopted at N2. The purpose was to include training in individuals' performance goals.

- Morale: After several management changes and three severences, workers have uncertainty about the site's long-term future. Workers are also experiencing an increasing pressure to reduce production costs. This sentiment is more prominent among exempt workers than among non-exempt, creating a potential challenge to implement the changes proposed by this study.

- Communication: More frustration and resistance mounts among operators as information flows unidirectional from top management. Frequently, information does not reach operators because middle management's failure to disperse it throughout the company. For instance, managers seldom inform operators about N2's performance metrics. Another example is the overlap of roles and responsibilities, making it difficult to determine the decision-making person. Nevertheless, some important changes were made to improve communication after this study was completed. For instance, the daily shift meetings were instituted to communicate metrics.

2.4.2. W5 Coating Plant:

Located in Waltham, this site produces along with New Bedford 1 a significant volume of Polaroid's Instant Film (Integral, Pocket, and Peel-apart). More specifically, it produces the positive and a layer for the negative film, the only step of the negative film production done outside of NB1. Compared to N2, production volumes at W5 are significantly higher.

2.4.2.1. Product Families

- L- Coat: At W5, all negative film receives a coat to stop the developing process that is called the L-Coat. Once a product has received this coating, it is shipped to NB1, where production is completed.

Raw materials for this product family includes two chemicals prepared and dispensed at Waltham 8 (W8), and a base material obtained from an outside vendor. The

chemicals are an aqueous and solvent fluids that are produced in large batches as expiration time are of no concern.

L-Coat passes twice through a coating line called coating line #9 (see Figure 3). After the first coat, the product is stored inside an automatic warehouse until a second pass is scheduled. The product is shipped to NB1 for its final processing after receiving the second coat. Different from Clear Sheet, L-Coat does not require slitting after all layers are applied.

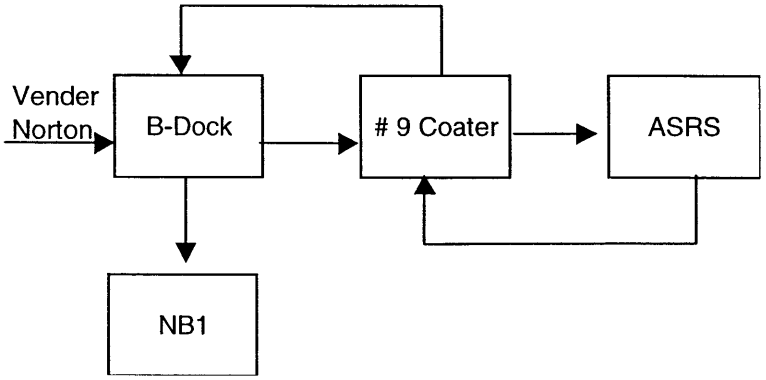


FIGURE 3: L-Coat process flow

Reliability is a problem at W5 as coating line #9 equipment, which includes one coater and five dryers, is over 25 years old. Furthermore, whenever #9 coating line is down for repairs, the other 2 coating lines cannot run halting the entire production since the former maintains the environmental emissions requirements of the plant.

- Clear Sheet: (Also known as Integral positive) W5 is the plant that supplies the positive for the integral film in different sizes.

Chemicals used at W5 are prepared and dispensed at Waltham 8 (W8). With the introduction of new businesses, some fluids will be bought from outside vendors, limiting W8's role to only dispensing.

Figure 4 shows the process flows for Clear Sheet. The product goes through a coating line that has two applicators called #10 and #10A. The product passes first through #10 coating the back of the positive film. The film is stored for some time in an automatic warehouse until it is passed through #10A that coats the front of the positive film The product is then moved to a slitting room, where it is cut down to a desired format. Finally, it is shipped out to the customer.

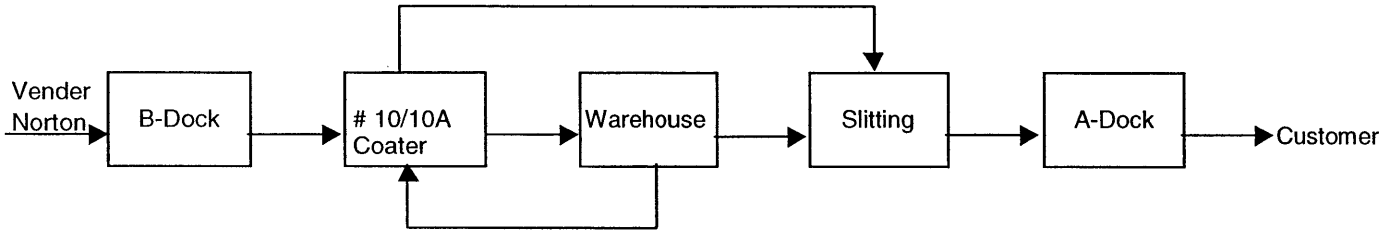


FIGURE 4: Clear Sheet process flow

Coating lines #10 and #10A are largely limited by two factors. First, they cannot run until coating line #9 has adjusted the environmental emissions levels, subjecting them to periods of low production. Second, the equipment is unreliable.

2.4.2.2. *Performance Metrics*

Yields at W5 are relatively high. The overall YTD (7/00) FPY is in the low 90%'s with coating line #9 in the high 80%'s and coating line #10 in the high 90%'s. The most common problem in general is streaks; although for coating line #9, base material and equipment problems account for most of the yield lost.

Utilization rate at W5 is mixed since coating line # 9 has a higher utilization than coating line #10. Hence, efforts have been concentrated on attracting new businesses for coating line #10. As a result of such effort, the utilization of coating line #10 grew by 7% compared to a 4% growth for coating line # 9.

2.4.2.3. *Working Environment*

- Expertise Level: high skilled operators who have worked there for more than 20 years characterize this site. As a matter of fact, cross-training has further increased their skills. Since 1988, operators carry out all the changeover work, including tasks that were assigned to mechanics. The changeover time was reduced, as operators no longer have to wait for mechanics to set up the equipment.

- Training: As with N2, formal training activities is minimum. Although a rotational program existed 5 years ago, training nowadays is done peer to peer. Nevertheless, the fact that operators are highly skilled allows them to be cross-functional.

- Morale: Workers are finally adjusting to the new work environment after so many restructures. Morale varies from shift to shift; but in general, employees are committed to make W5 succeed.

- Communication: Communication is also done from top management to operators. However, the constant presence of product and operation managers on the floor accounts for a closer communication with operators, at least during the day shifts. The presence of middle managers on the floor allows them not only to become aware of problems, but also to communicate business needs. For instance, site metrics such as yield, cycle time, and utilization are posted at the entrance of the building.

2.4.3. NB6 Coating Plant:

The newest of the 3 plants, its original purpose was to produce medical and imaging products (highly specialized products). However, their market never matured leaving Polaroid with sophisticated underutilized machines. During the past years, Peel-apart color coating has been moved to this site to increase utilization. Another product made at this site is printed TM (PTM), which is used for documents such as security badges. Production of PTM is customized and has relatively low volumes; but the company plans to increase its production volume. The high volume products at NB6 are Medical and Color Sheet.

2.4.3.1. *Product Families*

- Medical Sheet: This product is manufactured approximately 3 runs per year, each lasting 2 weeks. Expectations are for production volumes to further decline within the next 2 years.

  Similar to N2, all chemicals required for this product family are prepared and dispensed from the site's Chemical Mix area in bulk quantities. However, the base material comes from an outside vendor.

  The process flow for Medical Sheet (see Figure 5) includes running a base material through a coating line called #11X. Once the roll is completed, it is stored in a warehouse for periods of days or months, until it reaches a certain age necessary for its final quality. The final roll is slit and cut into plaques. A final inspection is performed before packaging, which is the final step before shipping to customers.

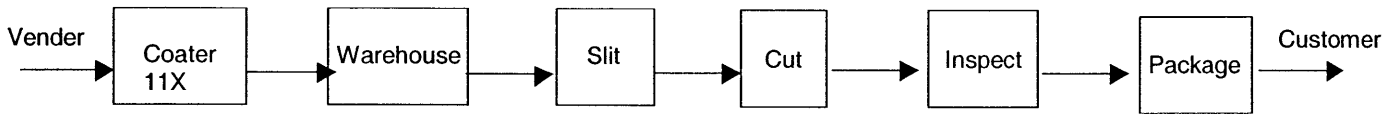


FIGURE 5: Medical process flow

Despite the 10 year experience with this product family, production has low yields. As with Print Coat, the production process is very complex and flooded with constant problems. A critical step for the yields is the cleanliness of the machine and the production area. Consequently, cleaning during changeover is extensive.

- Color Sheet: NB6 currently produces the entire positive Peel-apart color sheet for Vale, Mexico and Waltham 3. These products were brought from Waltham 1 (W1) in 1997 as part of a consolidation effort.

  Chemicals for this product family are also dispensed from the internal Chemical Mix area. The base material goes through coating line 11X and then it is inspected. Afterwards, the roll is slit and cut into different sizes (see Figure 6). The roll may be

store in a warehouse between coating and slitting until the slitter is freed up. Contrary to Medical Sheets, this product has neither a shelf life nor the need to age.

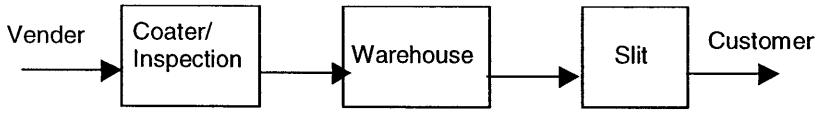


FIGURE 6: Color Sheet process flow

2.4.3.2. *Performance Metric*

Achieving the yields the peel apart product had originally at W1 has been the major challenge. Yields have improved for the past year thanks to practice and management commitment. For some Color Sheet products, yields have almost doubled. For instance, the FPY increased up to 6% over the past year. However, more improvements are necessary to reduce costs, particularly for Medical Sheet whose yields are still below 55%.

Utilization has also improved by 6% over the past year with the introduction of new products; yet, it is still under 85% equipment utilization.

2.4.3.3. *Working Environment*

- Expertise Level: Labor force is young and energetic. Overall, the expertise level is dispersed for all functional groups; but for the last 2 years, junior operators have had a fast learning curve, catching up with senior operators.

- Training: Similar to the other 2 coating plants, formal training activities is practically non-existent, as well as cross-training. Most job training is done peer to peer.

- Morale: Workers are uncertain about the long-term future of the site. The manpower was reduced by ~50% and more layoffs are feared as production volumes for Medical Sheets continue to drop. The thought of consolidation with another site creates resentments as workers consider themselves "different" from other sites.

- Communication: The flow of information is similar to other coating sites from top management to operators. On the other hand, written documentation is efficient and well managed.

	N2	W5	NB6
Product Families	• Printcoat • Coaterless • Some contracts	• L-Coat • Clear Sheet • Outside contracts	• Medical sheets • Color sheets • Introducing new products
Characteristics	• Products for professional photographers	• Products for average customers	• Products for Health facilities
Volume	• Medium volumes	• High volume	• Medium to low volumes
Base Material	• Outside supplier	• Outside supplier	• Outside supplier
Chemicals	• In-house dispensing and processing	• Dispensing and processing by another Polaroid site.	• In-house dispensing and processing
Modules	• Flexible /Interchangeable	• Fixed	• Flexible/Interchangeable
Complexity*	• High	• Low	• Medium
Operators' expertise	• Very high • Workforce with 10 + years of experience	• Very high • Workforce with 20 + years of experience	• Dispersed • Fast learning curve
Operators morale	• Medium to low	• Medium	• Medium
Employee age	• 49% of all employees between ages 51-60	• 50% of all employees between ages 51-60	• 38% of all employees between ages 41-50
Setup duration	• 8-12 hours	• 2-4 hours	• 1-2 days
Challenges	• Product uncertainty	• Low equip. reliability • Interdependency between coating lines	• Cleanliness of working environment/process
Communication	• Unidirectional top-down • Middle management fails to disperse information	• Unidirectional top-down • Varies from shift to shift shifts	• Unidirectional top-down. • Workforce feels like a separate group

*Complexity defined as the number of different coating techniques performed simultaneously

TABLE 1: Coating plants characteristics

2.5. Changeover Practices at Polaroid's sites

Changeover represents a critical step for Polaroid's coating facilities because a few coating lines manufacture hundreds of products. Depending on the coating site and the product, setups may take anywhere from 48 hours to 40 minutes during which machines are down or running dummy material to set new parameters or recipes.

2.5.1. N2's Changeover Practices:

For most products, the coating line runs for one-week periods to minimize changeovers. Workers still view this time as a "break" between runs and as an unwanted hectic operation. Management has recognized the need to change this set of mind with new strategies such as one-piece flow production. However, these new ideas are not yet part of everyone's vision.

Although the equipment is modular, the setup time lasts on average 8 hours during which Operations completes the cleaning, threading the web, running the leader and the paperwork. Simultaneously, Trades exchanges the modules and rolls, re-configures the oven and completes other mechanical inspections; and the Chemical Mix area delivers the necessary chemicals including cleaning solutions and coating fluids.

2.5.2. W5's Changeover Practices:

W5 had several efforts to improve its changeover time, and compared to N2 and NB6, the changeover duration is shorter from 2-4 hours. In addition to the streamlining efforts, W5 has other factors such as coater configuration, type of products run, and efficiency of the labor force that explain the shorter changeover time. Therefore, observations and data collection served a double purpose: first, to identify ways to further improve the setup time, and second, to identify practices for internal benchmarking.

Some of the specific characteristics of the coating lines at W5's that influence the changeover process are:

- The web path on coating line #9 never changes.
- Small teams of operators run each coating line. Coating line #10 operators can run coating line #9, but not vice versa.
- Coating line # 10 can run without coating line #10A, but not the other way around.
- Coating line #9 regulates the environmental emissions levels for the entire site.

- Although applicators at each coating station are modular, coating stations cannot be exchanged as in N2.

Currently, the setup process at W5 involves:

- Approximately a 4-hour period of preparation for the changeover, which includes cleaning modules and changing filters while the machine is running production. Operators are responsible for these two tasks.
- Operations also carry out the process of cleaning rolls, completing paperwork, threading the web, and running the substitute material.
- Exchanging applicators which was performed by Mechanics until Operations was trained to do it.
- Delivery of cleaning solutions and fluids, which is done by the external Chemical Mix area (W8).

It is important to mention at this point that W8 has been able to respond on time to W5's needs. However, W8 is being stretched to the limit because it has a reduced manpower to less than its minimum requirements. One advantage for W8 is that almost all fluids can be prepared in advance and that it has means to store them; enough backups exists to schedule cleaning time in advance.

2.5.3. NB6's Changeover Practices:

Production in general runs for periods of one to two weeks to reduce the number of changeovers, which are considered time consuming. Today, changeover lasts from one to two days. The division of labor during a changeover at this site is similar to that at N2. The process involves:

- Operations completes the following steps: cleaning, completing paperwork, threading the web, exchanging the modules and rolls, configuring the oven and running the leader.
- The Chemical Mix area is responsible for delivering cleaning solutions and fluids.
- Mechanics carry out any mechanical inspection needed and set the applicator.

NB6's changeover is extensive and complex due to the cleanliness requirements of the products, the complexity of its machine and the current division of labor. These issues have

not been a problem in the past since the machine was built for a couple of high volume products.

2.6. New Directions for Coating Sites

As specified by Polaroid's CEO during the announcement of year 2000-4th quarter expectations, Polaroid is adopting steps to increase cash flow and reduce spending. Such actions will generate cash, reduce debt by at least $100 million, fund new products, and shield the company from an extended economic downturn. Some of them include [8]:

- Sell underutilized real estate, such as the Reservoir property at Waltham
- Reduce excess manufacturing capacity and lower corporate overhead
- Lower working capital (inventory and accounts receivable)
- Reduce capital expenditures and refine new product development effort
- Accelerate digital printing strategy

The above actions have direct impact on the three coating plants because excess capacity, long production runs, high inventories and underutilized equipment characterize them. Several options exist to achieve the proposed goals. A controversial measure could be to consolidate all 3 coating facilities. However, unique capabilities and processes could be lost with a consolidation. Other options to achieve these goals include increasing flexibility and efficiency at each coating plant.

2.7. Literature review

Although literature on changeover reduction and its benefits is extensive for the auto industry, none was found for the coating industry using the following search strategy: the MIT library database was searched combining the terms: coating, changeover, SMED. The auto industry developed the SMED as part of the Just In Time (JIT) methodology to improve setup times. The SMED paradigm can benefit the coating principles because the methodological principles are broad and have been successfully extrapolated to other industries.

SMED focuses on increasing line flexibility and quick changeover by applying specific theories and techniques. Although the ultimate goal of SMED is to complete a changeover process in less than 10 minutes, not all industries accomplish it. In spite of that, dramatic reductions in changeover times are possible. It is another valuable improvement approach that any industry should adopt. As Kenichi and

Keisuke state in the book Kaizen for Quick Changeovers: "The concept of quick changeovers has done more to enhance the manufacturing process than any other improvement approach [9]."

According to Shingo, the methodology of SMED consists of [10]:

1) A preliminary study of the actual changeover process to distinguish internal and external activities. Internal activities are steps that are completed during the changeover and external activities are steps that are completed while the machine is running. Methods of conducting the preliminary study include interviews with operators and direct observation of the changeover process. The use of videotaping is helpful as the process can be reviewed and analyzed step by step.

2) Internal activities are separated from external ones, so the latter are carried out while the machine is running, saving time during the changeover. For example, rather than preparing parts after the machine has stopped and the changeover process is underway, they should be ready while the machine is running.

3) All internal activities identified as convertible should be turned to external, which can reduce setup time by 30-50%. Procedures should be established to help operators complete all external steps ahead of time. In addition, commitment, training, and documentation are essential for implementation.

4) Finally, all processes should be streamlined and standardized.

The positive results of SMED have been well documented. Toyota Motor Company shortened its changeover time from 8 hours to 58 seconds [11]. Another example is the marked reduction of changeover time at Mitsubishi Heavy Industries from 24-hours to 2 minutes and 40 seconds [12]. Why has changeover reduction not been pursued more vigorously by the coating industry? First, people are skeptical about the possibility of carrying out a changeover operation that takes hours in minutes. "Indeed, resistance can be greatest among those with long years of practical experience [13]." Managers find it easier to continue with current practices rather than dealing with resistance and push back from operators. Second, managers have found an artificial solution to the problem of inefficient changeovers by applying the concept of economic lot size. "If a large order is received, large-lot production will pose no particular problems because the effect of changeover time is slight when divided by the operating time

for each unit product. The greater the setup time, the more effective are the results of increasing the lot size [14]."

However, the aftermath of large-lot production is an excess of anticipated capacity, leading to increased inventories, higher costs, falls in capital turnover, and possibly goods becoming obsolete. The strategy of economic lot size may lower the costs associated with long setup times; but overall, it raises the costs by increasing inventories (See Figure 7 and Appendix A). Excess capacity also exerts no pressure to reduce changeover time, a phenomenon observed at the three Polaroid coating facilities. Operators perceive the changeover process as a "break" and not as a downtime operation. [34]

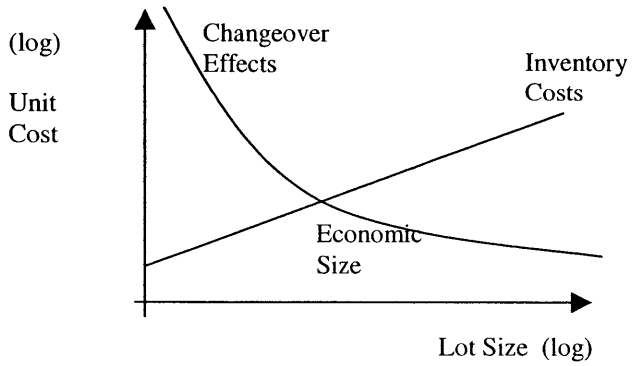


FIGURE 7: Large lot size effects

Aside from reduced inventories and increments on capital turnover, other reasons support a reduction in changeover time. "SMED facilitates product changeovers, thereby making it possible to respond rapidly to changes in demand and substantially increasing manufacturing flexibility [15]." New attitudes are created among workers when changeover reduction is proven. As a Hitachi manager said after reducing changeover time by more than 50%, "...the thing I was most keenly aware of was making the impossible possible." "The SMED system is much more than a matter of technique; it is an entirely new way of thinking about production itself [16]." Other reasons include the following:

- Elimination of unusable stock resulting from mistaken estimates of demand
- Minimal product deterioration during storage and handling
- Customer satisfaction with mix production of various types of goods
- Efficient usage of real estate
- Increased production capacity
- Minimization of changeover errors
- Quality improvements

- Simpler setups result in safer operations
- Simplification of procedures
- Job satisfaction with work simplification
- Reduction in workforce's skills and numbers with standardization

Changeover should be viewed as a waste that ought to be reduced or better yet, eliminated. Womack defines waste as any:

> " ...activity which absorbs resources but creates no value; mistakes which require rectification, production of items no one wants so that inventories and remaindered goods pile up, processing steps which aren't actually needed, movement of employees and transport of goods from one place to another without any purpose, groups of people in a downstream activity standing around waiting because an upstream activity has not delivered on time, and goods and services which don't meet the needs of the customer [17]."

" With the intense competition in industry today, simply meeting or beating past performance will not result in the level of improvement necessary to remain competitive [18]. No organization has the time or the resources to make mistakes, particularly if they can be avoided. Organizations must look outside themselves to learn the best practices achieved by someone else, although sometimes the best practices have been achieved within the company, but are not shared across sites. "It is good practice to look within your organization to see how other departments, functions, divisions, and/or locations are using the benchmark item before you start contacting 'external' organizations [19]."

2.8. Chapter Summary

As this chapter shows, Polaroid's products have a significant level of complexity. Moreover, the coating plants that produce these products have unique processes, culture, coating practices and changeover procedures. Nevertheless, as the literature proofs, any complex or unique process can be made more efficient. Such is the purpose with the changeover process across the three coating plants. Following is a description of the current changeover practices at each plants and the identified opportunities for improvements.

3. Data

It is in this chapter where the reader can find all the data collected throughout the six-month period. First, a description of the changeover practices at each site are described in detail and second, a narration of the best practices learned through the internal and external benchmarking is presented. It is important to highlight that this chapter only presents the data. Chapter 4 will make recommendations to how to adopt the best practices and reduce changeover time.

3.1. Changeover Data

3.1.1. N2's Changeover Data:

Log sheets were analyzed and the changeover process was observed and videotaped with particular emphasis on the key steps to complete a module cleanup and to exchange a module/roll. The duration of each step was recorded as well as who completed the step: operators, machine, mechanics, Chemical Mix area, travel time.

Log sheets from 10/98 to 6/00 reveals the significant impact of changeover to N2's overall downtime. Although data had approximately a 2% noise, changeover represents about 50% of the downtime (See Figure 7).

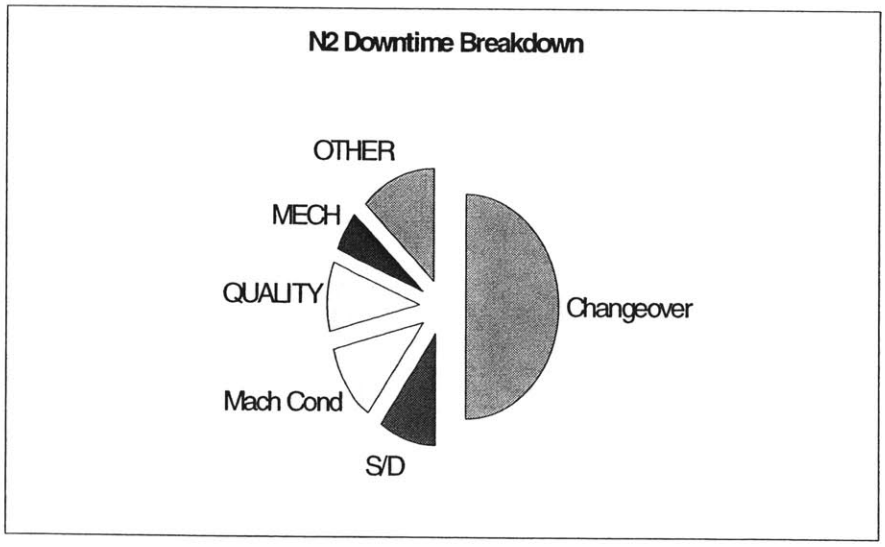
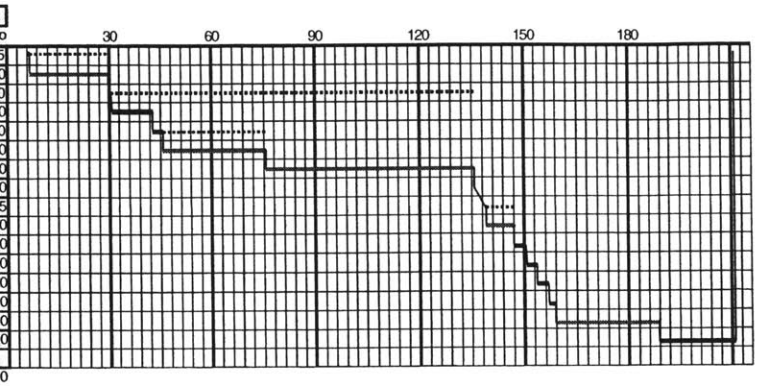


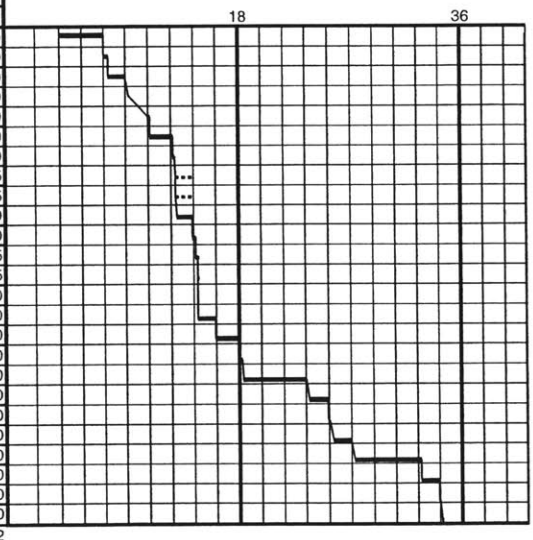
FIGURE 7: N2's Downtime

FIGURE 8: N2 Man-Machine charts

CAN BE	AS IS	PART:	Operators:		
		PROCESS: Operations module clean	TIME (min)		
		# OPERATION	Man	Walk	Auto
I	I	1 Turn knobs to flush lines	0.67	0	15
R	I	2 Wait for lines to flush	15	0	0
I	I	3 Turn knobs for cleaning sln	0.67	0	70
I	I	4 Rub/scrap/clean module	8	0	0
I	I	5 Run built-in pump to flush out most sln	2	0	20
R	I	6 Wait for pump 2-3 times	20	0	0
R	I	7 Wait for sln to run 2-3 times	40	0	0
R	I	8 Bring temp pump	0	2	0
R	I	9 Run temp pump to flush out all sln	0.33	0	5
R	I	10 Wait for pump	5	0	0
I	I	11 Open module and oven doors	2	0.3	0
I	I	12 Cut web	2	0.2	0
I	I	13 Remove all the pipes and lines	2	0.2	0
R	I	14 Remove bottom tray	0.67	0.2	0
R	I	15 Wait for mechanic to remove module	20	0	0
I	I	16 Scrap module	15	0	0
E= EXTERNAL		TOTAL TIME (MIN)	133	2.9	110
I= INTERNAL		WAIT TIME	100		
R= REDUCED		% OF TIME WAITING	75%		
		TOTAL TIME TO CLEAN MODULE	2.27 hr		
		By increasing flow rate of cleaning sln, cross training, and buying second pump we will reduce time by about 35%			
		Time saved:	35 min		



CAN BE	AS IS	PART:	Operators:		
		PROCESS: Mechanic module exchange	TIME {min}		
		# OPERATION	Man	Walk	Auto
R	I	1 Unscrew module (2 screws and circular motion)	4	0	0
I	I	2 Remove facility lines	1	0	0
I	I	3 Pull module out with lifter	0.5	1	0
E	I	4 Place module in maintenance base	0.2	1	0
E	I	5 Hook ropes to roll to be exchanged	0.5	0	0
E	I	6 Unscrew roll (4 screws)	2	0	0
E	I	7 Place hoist on top of roll and hook ropes	0.5	0.2	0
E	I	8 Lift roll	0	0	0.5
E	I	9 Place roll on rack	0	0.2	0.5
E	I	10 Untie rope from roll	0.5	0	0
E	I	11 Bring hoist to new roll	0.5	0.2	0
E	I	12 Tie rope and hook to hoist	0.5	0	0.5
E	I	13 Lift new roll	0	0	0.5
E	I	14 Bring roll to S1 module	0	0.2	0
E	I	15 Untie rope from roll	0.5	0	0
E	I	16 Screw roll	2	0	0
E	I	17 Foot print (connect air lines, place paper and lowe	1	0.5	0
E	I	18 Calibrate roll	5	0.5	0
E	I	19 2nd measurement/ Write info	1	0	0
E	I	20 Pull module out with fork lift	0.5	1	0
I	I	21 Place module in coater	0.5	1	0
R	I	22 Screw module in	6	0	0
I	I	23 Install facility lines	1	0	0
I	I	24 Place bottom tray	0.2	0.5	0
I	I	25 Close doors	0.2	0	0
		TOTAL TIME (MIN)	28.1	6.3	2
E= EXTERNAL		POTENTIAL EXTERNAL TIME	30.5		
I= INTERNAL					
R= REDUCED					



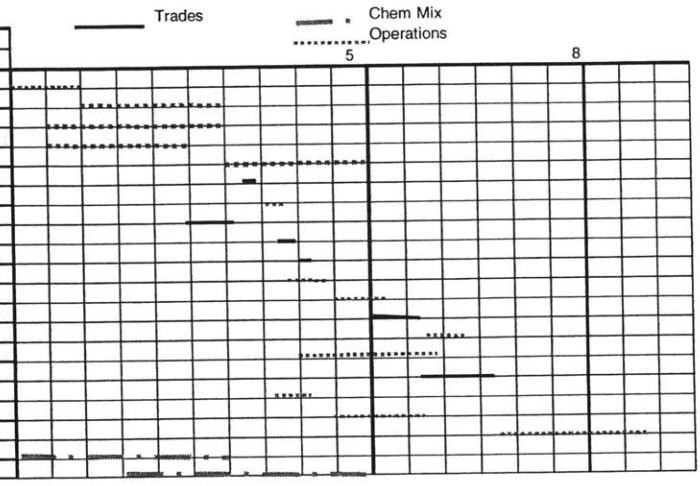
total time for EXCHANGE OF ONE ROLL ONLY 36.4 min

By fixing the schedule, having enough modules and rolls for swap and by reducing customization, the time will be reduced by ~ 90%

FIGURE 9: N2 Gantt Chart

Land Line

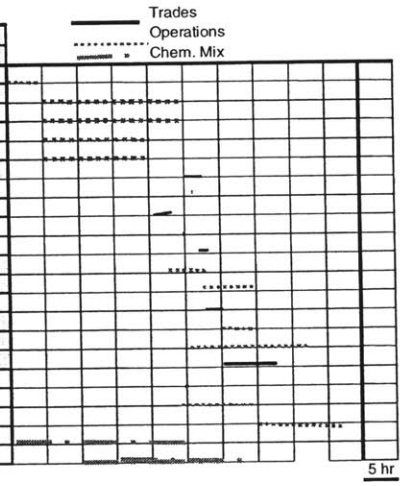
#	PROCESS: Changeover for 3 modules OPERATION	TIME {hr}
1	Shutdown machine, plan, do paperwork	1.0
2	Cut web and tape new path	2.0
3	Clean A1	2.5
4	Clean A2	2.0
5	Clean A3	2.0
6	Pull A1 out	0.2
7	Complete cleaning on A1	0.3
8	Pull A2 out, complete roll exchange, move into coate	0.7
10	Calibrate blade on A1	0.3
11	Move A1 back into coater	0.2
12	Bring A2 into operation	0.5
13	Bring A1 into operation	0.7
14	Pull A3 out,complete roll exchange, move into coate	0.5
16	Bring A3 into operation	0.5
17	Bring ovens back to temp	2.0
18	Complete other mechanical checks	1.0
19	Clean IS	0.5
20	Fill IS	1.0
21	Run leader	2.0
22	Provide cleaning slns	3.0
23	Provide fluids for next run	3.0



Assumptions
SCHEDULE:
Schedule changes allowed minimum preparation for Chem Mix
Schedule changes allowed minimum preparation for mechanics
COMMUNICATION:
Communication between mech and operat. is good
Communication with warehouse for leader is poor
ORGANIZATIONAL:
TWO operators cleaning on second floor and TWO on first floor
WORK METHODOLOGY
Oven temp brought down and then back
Material/tools scattered and not ready

FUTURE Land Line

#	PROCESS: Changeover for 3 modules OPERATION	TIME {hr} BEFORE	TIME {hr} AFTER
1	Shutdown machine, plan, do paperwork	1.0	0.5
2	Cut web and tape new path/ clean rolls	2.0	2.0
3	Clean A1	2.5	2.0
4	Clean A2	2.0	1.5
5	Clean A3	2.0	1.5
6	Pull A1 out	0.2	0.2
7	Complete cleaning on A1 (done offline, when machine running)	0.3	0.0
8	Pull A2 out. NO complete roll exchange (swap)	0.7	0.2
10	Calibrate blade on A1 NOT needed	0.3	0.0
11	Move A1 back into coater...the pre-assembled module	0.2	0.1
12	Bring A2 into operation	0.5	0.5
13	Bring A1 into operation	0.7	0.7
14	Pull A3 out. NO complete roll exchange (swap)	0.7	0.2
16	Bring A3 into operation	0.5	0.5
17	Bring ovens back to temp (procedure to leave ovens to med temp.)	2.0	2.0
18	Complete other mechanical checks	1.0	1.0
19	Clean IS...done as part of pre-planning	0.5	0.0
20	Fill IS (bigger lines will speed up process)	1.0	0.7
21	Run leader. Leader ready	2.0	1.5
22	Provide cleaning slns (pre planning allows to prepare ahead of time)	3.0	2.5
23	Provide fluids for next run (pre planning)	3.0	2.0



Assumptions
SCHEDULE:
Schedule changes notified ahead of time for Chem Mix to prepare
Schedule changes notified ahead of time for Mechanics to prepare
COMMUNICATION:
Communication between mech and operat. is good
Communication with warehouse for leader is good
ORGANIZATIONAL:
THREE operators cleaning on second floor and TWO on first floor
WORK METHODOLOGY
Oven temp brought down and then back
Material/tools READY before machine is shutdown
Enough modules to allow for swap; roll exchange done externally

The man-machine charts of Figure 8 show a breakdown of the changeover time by steps (*i.e.* applicator change, module cleanup and exchange); Figure 8 also details the duration of each step, the waiting periods, and who completes each step. Moreover, Figure 8 identifies all the internal steps that can be converted into external ones.

The Gantt charts of Figure 9, on the other hand, present the steps that are parallel or dependent on other steps. These charts also show the breakdown of responsibilities among the three functional groups: Mechanics, Operations and Chemical Mix. Moreover, they present the division of labor among the workers per shift of Operations: workers on the 1st floor shutting down the machine and operators on the 2nd floor doing the cleanup. Figure 9, however, does not account for the breaks that workers take during a shift.

The data identify dependencies among functional groups and work behaviors that affect the changeover time. Operators depend on mechanics to exchange modules because only the latter group is trained to use a airlift to carry out this task. Operators also depend on the Chemical Mix area to dispense fluids on time. Miscommunication prolongs waiting periods and delays the total changeover time. Finally, senior operators usually stay on the first floor where work is less intense and requires higher skills. Rotations between floors are non-existent due to limited cross-training.
Several non-value-added operations exist throughout the changeover process such as screwing bolts (see Figures 8 and 9).

What is the bottleneck operation during a changeover? Observations and data analysis show the existence of several bottleneck operations. Several factors define where a bottleneck operation would appear during the changeover process. As a whole, the bottleneck operation is a dynamic process that depends on multiple circumstances.

- Timing of the changeover: Chemical Mix could become the bottleneck of the changeover process if time is insufficient to prepare the chemicals that have a tight shelf life or, on the contrary, to allow chemicals achieve the appropriate aging. For instance, if a changeover is done in the middle of the week, the Chemical Mix area has enough time to prepare the fluids, thus transferring the bottleneck operation to another area. However, if the changeover is carried out on a Monday, the Chemical Mix area will not have time to prepare the fluids, unless employees work overtime on Sunday. Frustration was common among the Chemical Mix employees given the constant changes of schedule and their limited planning abilities.

- Schedule changes: Changing schedules can be problematic for mechanics if they have to change several modules or for the Chemical Mix area if they have to prepare fluids with specific aging requirements. Mechanics are the bottleneck operation during unscheduled changes of Coaterless production, while for the Chemical Mix area is during changes to the Printcoat schedules. With 2-3 days fixed schedules, both mechanics and operators at the Chemical Mix area can plan ahead their activities, avoiding waiting time and bottleneck operations.
- Operators' availability: Operations runs with more employees during a changeover than the Chemical Mix area and trades. If any worker is absent, significant delays in the setup may occur. Another important factor is the training level workers have.
- Unexpected problems: Aside from the above problems, other areas may become the bottleneck during the changeover. For instance, if continuous paper breaks occur during a leader run, Operations becomes the bottleneck area. On the other hand, mechanics may become the problem area if a pneumatic forklift breaks and a manual has to be used.

In summary, N2's changeover data show that it represents a significant part of the downtime and consumes considerable amount of resources. Large number of non-value added operations, failure to convert internal procedures into external activities, non-standardized procedures, and schedule unpredictability explains the 8-12 hour changeover processes. Figure 8 and 9 highlights the wastes and inefficiencies of the current practices. Chapter 4 offers solutions.

3.1.2. W5's Changeover Data:

The same methodology used at N2 was followed at this site to analyze the downtime and the changeover process (analysis of log sheets, direct observations, and videotaping).

Changeover data from last year and YTD (8/7/00) show that changeover times for coating lines #10 and #9 lasted on average 2 hours and 4 hours, respectively. These times are significantly shorter compared to N2's time (8 hours) and NB6's time (16 hours).
Log sheets from 1/99 to 8/00 were used to calculate what percentage the changeover process represented from the total downtime. For coating line #10, the changeover time represents 6% of the downtime compared to 11% of coating line #9 (see to Figure 10). Environmental and equipment problems were the main reasons for the downtime at this site.

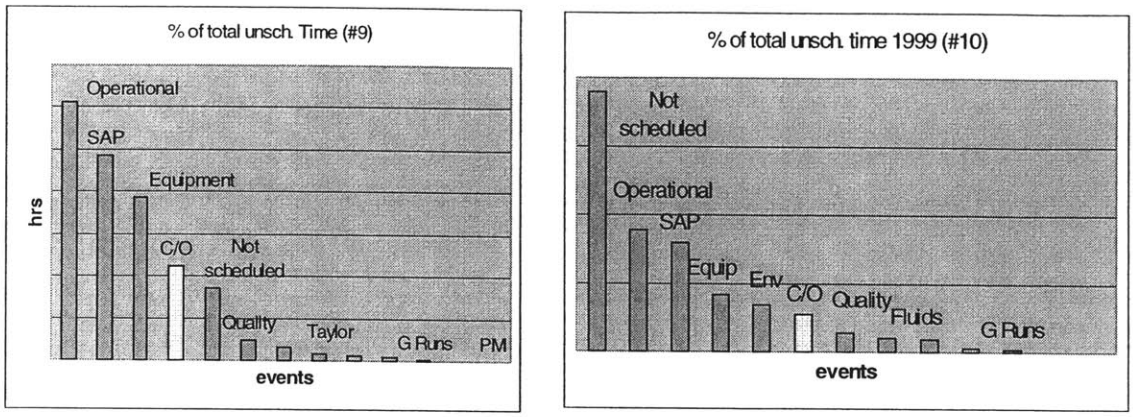


FIGURE 10: W5's Downtime

As observed, some key steps during the changeover process consume a significant amount of time (see Figure 11). For instance, screwing and unscrewing bolts represented 43% of the time to exchange an applicator of coating line #10 and 27% of the time to do the same with coating line #9. Twenty percent of the time exchanging an applicator in coating line #9 is non-value-added time such as cleaning and setting up a tray for the next run. Time to circulate fluids and to run the leader fluctuates significantly from minutes to hours.

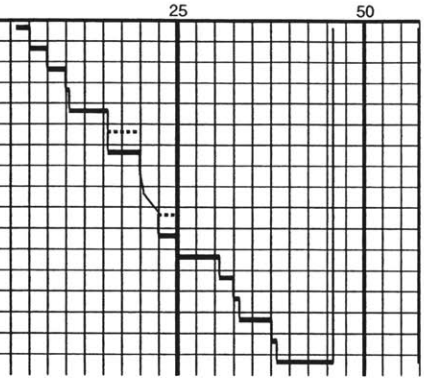
Figure 12 presents data where time can be saved during the changeover. For instance, non-value-added steps for coating line #9 such as looking around for tools, tapes, and other items, can be eliminated. The cleaning process is carried out manually and under poor working conditions such as dim lighting and locations inaccessible. Redefining the process by which the web is taped between coating line #10 and #10A can eliminate another non-value-added step. As seen in Figure 12, a 15% reduction of the changeover time could be achieved if these steps are implemented (see Chapter 4).

Similar to N2, the bottleneck operation is dynamic and depends on schedule changes, excursion, and availability of operators and resources. For instance, schedule changes may delay dispensing chemicals from the external W8 Chemical Mix area, although less significant if compared to N2. Excursions such as repairs or problems running the dummy material while setting parameters may create bottlenecks. If a shortage of operators or resources prevents cleaning the applicators while the machine is running, it has to be completed during the changeover, thus creating a bottleneck.

FIGURE 11: W5 Man Machine Charts

CAN BE AS IS PART: Change to Elsie 8/10/00 — Operators:

		#	PROCESS: #10 applicator exchange	TIME {min} Man	Walk	Auto
R	I	1	Screw crane support to applicator	1	0	0
R	I	2	Unscrew bolts (4) on each side of the applicator	2	0	0
I	I	3	Position the crane	2	0	0
I	I	4	Remove the fluid lines from each side of the applicator	1	0	0
eliminatec	I	5	Remove the bottom pipes and foot	5	0	0
I	I	6	Lift applicator and place it in storage box	0	0	3
R	I	7	Wait for crane	3	0	0
I	I	8	Transfer applicator to cleaning room	0	1	0
I	I	9	Transfer new applicator to crane	0	1	0
I	I	10	Lift applicator to the coater	0	0	3
I	I	11	Wait for crane	3	0	0
eliminatec	I	12	Screw pipe and foot to the side of applicator	5	0	0
I	I	13	Position applicator	1	0	0
R	I	14	Screw (4) bolts back to each side	2	0	0
R	I	15	Calibrate gap	3	0	0
I	I	16	Set gap wheel (bottom of applicator)	1	0	0
I	I	17	Complete fluid line exchange	7	0	0
			Total individual times	36	2	6
			Total time	44		
			Time removing screws	19	43%	



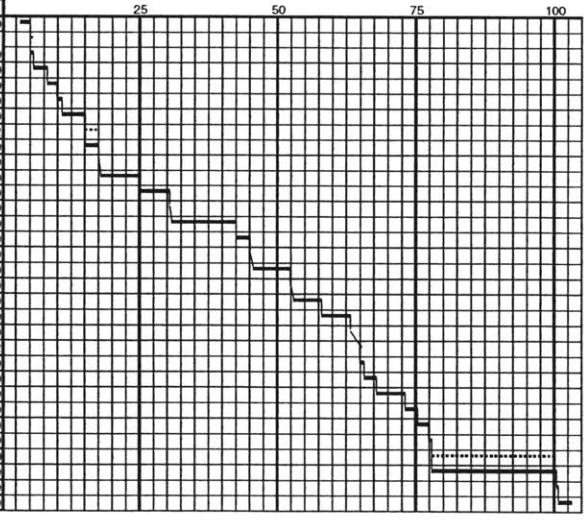
E= EXTERNAL
I= INTERNAL
R= REDUCED

EXCHANGE OF ONE APPLICATOR

One hr for fluids running/prep
One hr for leader run and bringing ovens to temp

CAN BE AS IS PART: Change to Aqueous 9/22/00 — Operators:

		#	PROCESS: #9 applicator exchange	TIME (min) Man	Walk	Auto
I	I	1	Remove fluid lines	1	0	0
I	I	2	Add solvent to try to dissolve fluid	0	0	1
I	I	3	Wait for solvent to run	1	0	0
R	I	4	Unscrew bolts (4) on each side of the applicator	2	0	0
I	I	5	Position the crane	1	0	0
eliminatec	I	6	Unscrew the pipe connection (4 screws)	2	0	0
eliminatec	I	7	Unscrew the applicator foot	3	0	0
I	I	8	Lift applicator and place it in storage box	0	0	2
I	I	9	Wait for crane	2	0	0
I	I	10	Transfer applicator to cleaning room	0	0.5	0
R	I	11	Drain all solution from tray	6	0	0
R	I	12	Remove tray paper	5	0	0
R	I	13	Dispose waste	0	1	0
E	I	14	Tape new paper to tray	10	0	0
R	I	15	Remove bottom of vacuum box	2	0	0
E	I	16	Take part to storage/bring new part	0	1	0
R	I	17	Remove vacuum box	5	0	0
R	I	18	Take part to storage/bring new part	0	1	0
R	I	19	Install new vaccum box	5	0	0
R	I	20	Install new bottom part for vacuum box	5	0	0
I	I	21	Transfer new applicator to crane	0	0.2	0
I	I	22	Lift applicator to the coater	0	0	2
I	I	23	Wait for crane	2	0	0
I	I	24	Position applicator	1	0	0
R	I	25	Screw back foot and pipe connection to the side of applicator	5	0	0
R	I	26	Screw (4) bolts back to each side	2	0	0
R	I	27	Calibrate gap	1	0	0
I	I	28	Set gap wheel (bottom of applicator)	1	0	0
R	I	29	Test fluids at W8	0	0	20
R	I	30	Wait for fluids	20	0	0
I	I	31	Run new fluids to tray to check	1	0	0
I	I	32	Connect new fluid lines	2	0	0
			Total time	85	3.7	25
				114		
			Time removing screws	31	27%	
			Time cleaning	23	20%	



E= EXTERNAL
I= INTERNAL
R= REDUCED

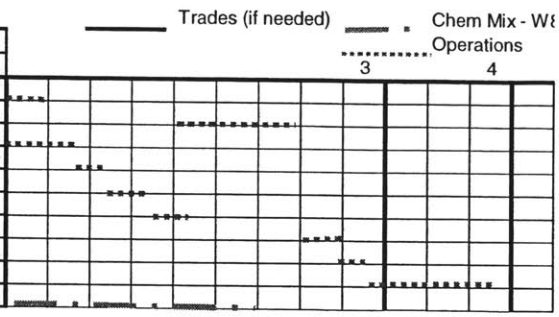
One hr for leader run and bringing ovens to temp

Does not include roll cleaning. Ex. chiller, air rolls. This is done when the operators identify build up that needs to be removed

FIGURE 12: W5 Gantt Chart

 # 9 coating line TODAY

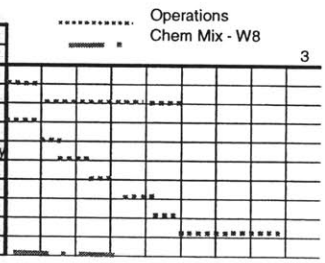
#	PROCESS: Changeover for 1 applicator OPERATION	TIME {min}
1	Shutdown machine, plan, do paperwork	20.0
2	Clean/check rolls	60.0
3	Clean tray/module	35.0
4	Remove applicator	15.0
5	Change vacuum box	20.0
6	Install new applicator	15.0
7	Run fluids	20.0
8	Check parameters	10.0
9	Run leader	60.0
10	Provide fluids for next run	120.0



Assumptions
SCHEDULE:
Schedule made to optimize #9 and W8 operations
COMMUNICATION:
Communication between W8 and operat. can be improved
Communication with warehouse for leader is good; material ready
ORGANIZATIONAL:
ONE operator on break
TWO operators to clean tray and swap applicator
WORK METHODOLOGY
Material staged and ready before changeover
Tools scattered and not centralized

 # 9 coating line FUTURE

#	PROCESS: Changeover for 1 applicator OPERATION	TIME {min} BEFORE	TIME {min} AFTER	comment
1	Shutdown machine, plan, do paperwork	20.0	20.0	
2	Clean/check rolls	60.0	60.0	
3	Clean tray/module	35.0	20.0	eliminate manual draining
4	Remove applicator	15.0	12.0	tools ready
5	Change vacuum box	20.0	15.0	tools and new vacuum box ready
6	Install new applicator	15.0	12.0	tools ready
7	Run fluids	20.0	20.0	
8	Check parameters	10.0	10.0	
9	Run leader	60.0	60.0	
10	Provide fluids for next run	120.0	60.0	

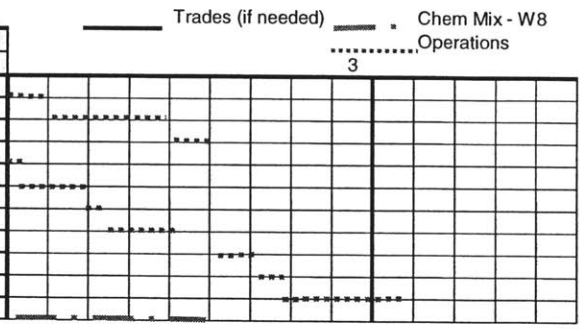


Assumptions
SCHEDULE:
Schedule made to optimize #9 and W8 operations
COMMUNICATION:
Communication between W8 and operat. IMPROVED: FLUIDS READY WHEN NEEDED
Communication with warehouse for leader is good; material ready
ORGANIZATIONAL:
ONE operator to shutdown machine and clean rolls IMMEDIATELY
TWO operators to clean tray and swap applicator
WORK METHODOLOGY
Material staged and ready before changeover
TOOLS ORGANIZED

FIGURE 12: W5 Gantt Chart cont.

 # 10 coating line TODAY

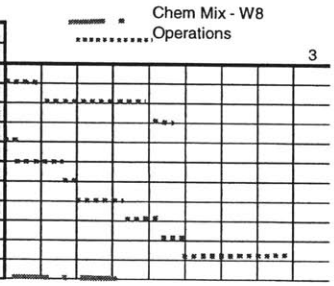
#	PROCESS: Changeover for 2 applicators OPERATION	TIME {min}
1	Shutdown machine, plan, do paperwork	20.0
2	Clean/check rolls	60.0
3	Cut web and tape new path	20.0
4	Clean 10A	5.0
5	Change applicator on #10A	35.0
6	Clean #10	5.0
7	Change applicator on #10	35.0
8	Run fluids	20.0
9	Check parameters	10.0
10	Run leader	60.0
12	Provide fluids for next run	100.0



Assumptions
SCHEDULE:
Schedule made to optimize #10 and W8 operations
COMMUNICATION:
Communication between W8 and operat. can be improved
Communication with warehouse for leader is good; material ready
ORGANIZATIONAL:
ONE operator to shutdown machine and clean rolls
TWO operators to tape web and swap applicator
WORK METHODOLOGY
Material staged and ready before changeover
Tools scattered and not centralized

 # 10 coating line FUTURE

#	PROCESS: Changeover for 2 applicators OPERATION	TIME {min} BEFORE	TIME {min} AFTER	comment
1	Shutdown machine, plan, do paperwork	20.0	20.0	
2	Clean/check rolls	60.0	60.0	
3	Cut web and tape new path	20.0	10.0	Find better approach to do it
4	Clean 10A	5.0	5.0	
5	Change applicator on #10A	35.0	32.0	tools ready
6	Clean #10	5.0	5.0	
7	Change applicator on #10	35.0	32.0	tools ready
8	Run fluids	20.0	20.0	
9	Check parameters	10.0	10.0	
10	Run leader	60.0	60.0	
12	Provide fluids for next run	100.0	60.0	



Assumptions
SCHEDULE:
Schedule made to optimize #10 and W8 operations
COMMUNICATION:
Communication between W8 and operat. IMPROVED: FLUIDS READY WHEN NEEDED
Communication with warehouse for leader is good; material ready
ORGANIZATIONAL:
ONE operator to shutdown machine and clean rolls
TWO operators to tape web and swap applicator
WORK METHODOLOGY
Material staged and ready before changeover
TOOLS ORGANIZED

3.1.3. NB6's Changeover Data:

Observations and data collection followed the same methodology as described above. Changeover times lasted on average 2.5 days in 1999, but were shorter for this year (up to 7/31/00) lasting on average 1.7 days.

Contrary to N2 and W5, NB6 does not record individual downtimes. Data recording is limited to utilization numbers and changeover duration. Because no data was available for downtimes due to equipment failure or problems with the coating process, an analysis could not be done on how much the changeover process represents from the total downtime. However, interviews conducted during the observation period of the study and utilization reports strongly suggest that the changeover process is an important contributor of the downtime at NB6.

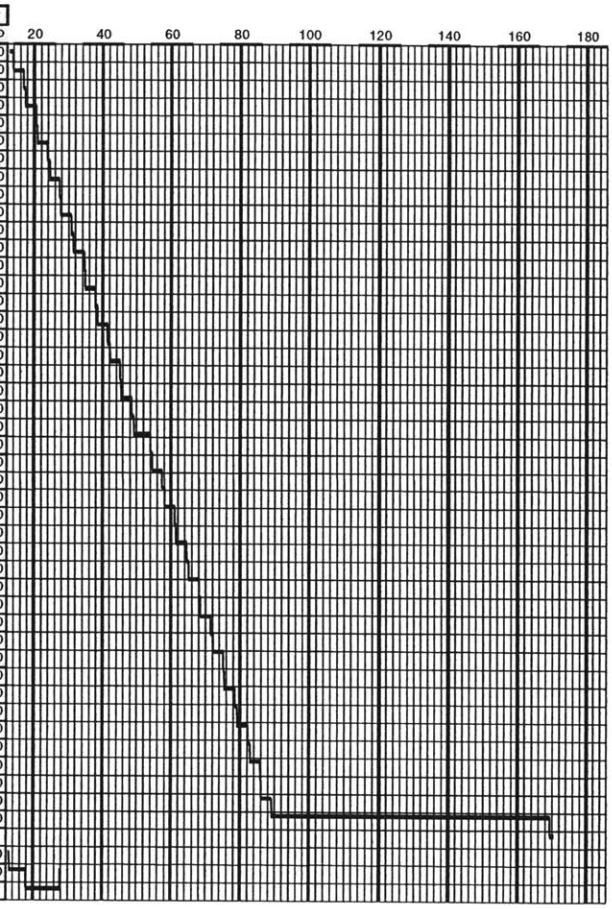
Figure 13 shows the duration of each key step during the changeover process: module cleanup, applicator exchange, and oven cleanup. Two steps were identified as the longest: cleaning applicators during the applicator exchange and changing nozzles during the oven cleanup. Because the number of applicators and nozzles varies with each product, a direct comparison between the total time that takes to complete each step could not be done. However, cleaning a single applicator takes on average 4 hours while changing 10 nozzles takes 36 minutes on average.

Compared to N2 and W5, NB6's changeover process is the most complex one. Several activities occur in parallel, are interdependent, and take large amounts of time (see Figure 14). There are multiple bottleneck operations, some of which take days to be completed. For instance, the Chemical Mix area needs to conduct thorough cleanings to avoid contamination in between runs. No dedicated vessels exist for the aqueous or the solvent cleaning systems, and cleaning each vessel takes between 3 to 4 hours. This means that for the P6 product cleaning all 10 vessels takes between 30 to 40 hours. The shortest cleanup time is for Medical Sheets that takes between 9 to 12 hours.

Mechanics also play an important role in the duration of the changeover. Operations may have to stop their activities if mechanics are not present at the appropriate time to setup the applicator gap. Finally, because no cross training exists, the absence of a worker may delay the entire changeover process.

FIGURE 13: NB6 Man Machine Chart

CAN BE	AS IS	#	OPERATION	TIME {min} Man	Wal	Auto
		PART:		Operators:		
		PROCESS: Nozzle change and cleaning of oven				
I	I	1	Get inside the oven	1	0	0
R	I	2	Remove nozzle	3	0	0
I	I	3	Hand nozzle to operators outside	0.5	0	0
R	I	4	Remove nozzle	3	0	0
I	I	5	Hand nozzle to operators outside	0.5	0	0
R	I	6	Remove nozzle	3	0	0
I	I	7	Hand nozzle to operators outside	0.5	0	0
R	I	8	Remove nozzle	3	0	0
I	I	9	Hand nozzle to operators outside	0.5	0	0
R	I	10	Remove nozzle	3	0	0
I	I	11	Hand nozzle to operators outside	0.5	0	0
R	I	12	Remove nozzle	3	0	0
I	I	13	Hand nozzle to operators outside	0.5	0	0
R	I	14	Remove nozzle	3	0	0
I	I	15	Hand nozzle to operators outside	0.5	0	0
R	I	16	Remove nozzle	3	0	0
I	I	17	Hand nozzle to operators outside	0.5	0	0
R	I	18	Remove nozzle	3	0	0
I	I	19	Hand nozzle to operators outside	0.5	0	0
R	I	20	Remove nozzle	3	0	0
I	I	21	Hand nozzle to operators outside	0.5	0	0
R	I	22	Wait for new nozzle	5	0	0
I	I	23	Receive new nozzle	0.5	0	0
R	I	24	Install new nozzle	3	0	0
I	I	25	Receive new nozzle	0.5	0	0
R	I	26	Install new nozzle	3	0	0
I	I	27	Receive new nozzle	0.5	0	0
R	I	28	Install new nozzle	3	0	0
I	I	29	Receive new nozzle	0.5	0	0
R	I	30	Install new nozzle	3	0	0
I	I	31	Receive new nozzle	0.5	0	0
R	I	32	Install new nozzle	3	0	0
I	I	33	Receive new nozzle	0.5	0	0
R	I	34	Install new nozzle	3	0	0
I	I	35	Receive new nozzle	0.5	0	0
R	I	36	Install new nozzle	3	0	0
I	I	37	Receive new nozzle	0.5	0	0
R	I	38	Install new nozzle	3	0	0
I	I	39	Receive new nozzle	0.5	0	0
R	I	40	Install new nozzle	3	0	0
I	I	41	Receive new nozzle	0.5	0	0
R	I	42	Install new nozzle	3	0	0
R	I	43	Wipe/clean oven	100	0	0
I	I	44	Get outside the oven	1	0	0
R	I	1	Change shims (10)	5	0	0
R	I	2	Cover nozzle openings (8)	10	0	0



Total time 177

(shims done in parallel to cleaning)

Total time to remove/install 10 nozzles 36

Total time to clean the oven 100

E= EXTERNAL
I= INTERNAL
R= REDUCED

ONLY FOR 10 NOZZLES (BOTTOM NOZZLES)
PROCESS USUALLY INVOLVES CHANGING
FROM 30-50 NOZZLES PER OVEN.

CAN BE	AS IS	PART:	Operators:			
		PROCESS: Aqueous cleaning and exchange of applicator	TIME (min)			
		# OPERATION	Man	Walk	Auto	
I	I	1 Disconnect pipes	5	0	0	
I	I	2 Transport module to headroom	0	2	2	
R	I	3 Remove back pipes	1	0	0	
I	I	4 Remove applicator and place on table	2	0	4	
E	I	5 Disassemble applicator	5	0	0	
E	I	6 Transport both side to sink; each at a time (5 min each)	0	10	10	
E	I	7 Soak applicator in hot water	0	0	10	
R	I	8 Remove white extension for roll width	2	0	0	
R	I	9 Attach new extension for new roll width	4	0	0	
I	I	10 Clean module	3	0	0	
E	I	11 Scrub applicator and dry it	4	0	0	
E	I	12 Transport applicator to table	0	2	2	
E	I	13 Assemble applicator and check side gap	6	0	0	
E	I	14 Store applicator (racks)	2	0	0	
I	I	15 Transport roll to check gap	1	0	1	
I	I	16 Check gap	4	0	0	
I	I	17 Transport roll back to base	1	0	1	
I	I	18 Find new applicator and screw crane bolts	2	0	0	
I	I	19 transport applicator to module	0	4	4	
I	I	20 Screw applicator in place	2	0	0	
I	I	21 Remove crane bolts	1	0	0	
I	I	22 Complete torque on applicator bolts	2	0	0	
I	I	23 transport module to machine	0	2	2	
I	I	24 tape applicator	1	0	0	
I	I	25 Insert module to machine	0.5	0	0	
I	I	26 Connect fluid pipes and back pipe	7	0	0	
I	I	27 Verify checklist	0.5	0	0	
E= EXTERNAL		Total indiv times	56	20	36	
I= INTERNAL		Total time (min)	112			
R= REDUCED		Total time (hr)	1.87			
		Possible time eliminated by cleaning external	39 min			
		TIME FOR ONE APPLICATOR				

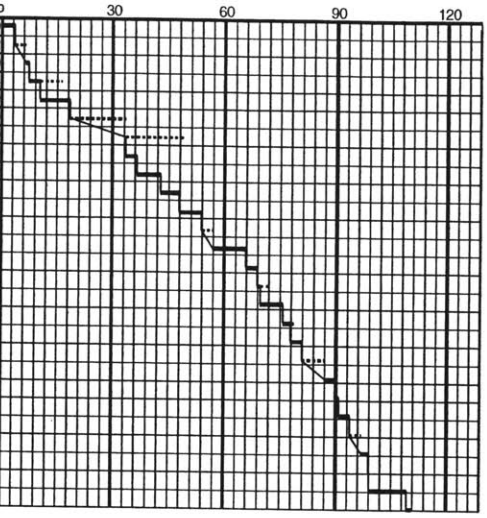
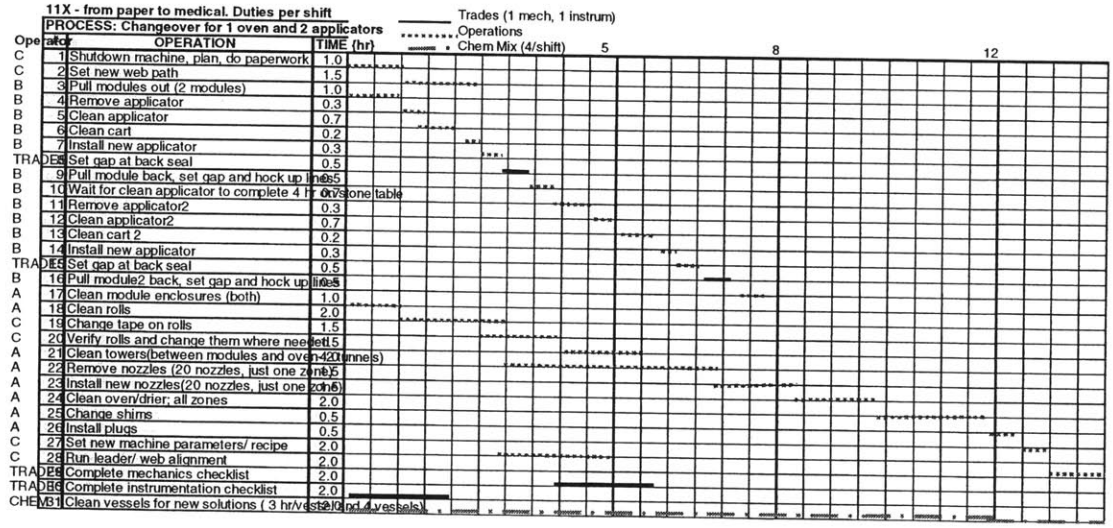


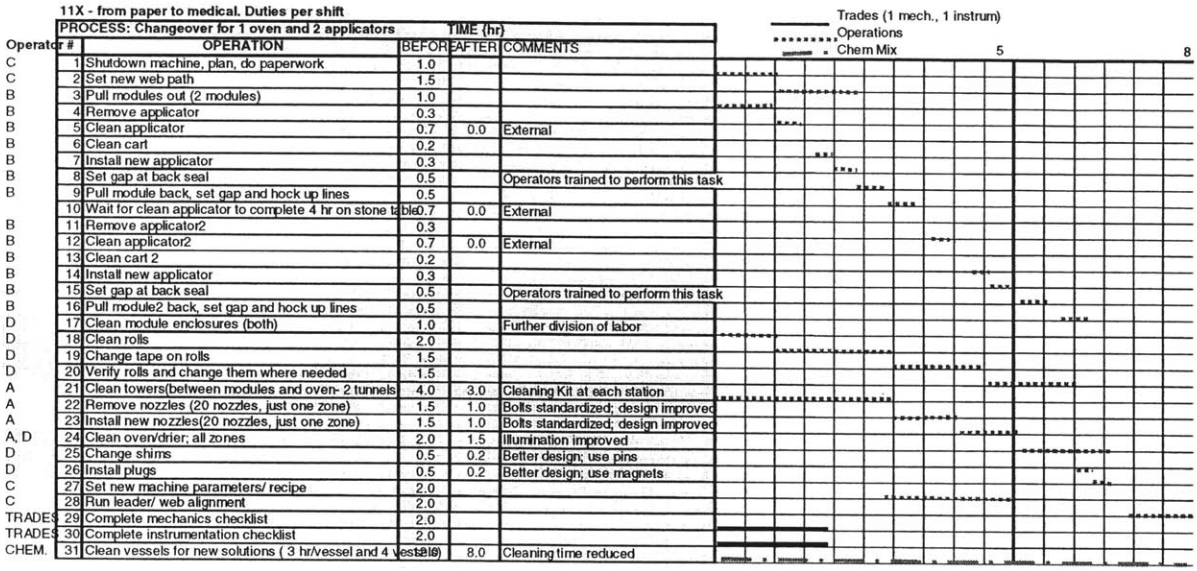
FIGURE 14: NB6 Gantt Chart



Assumptions
SCHEDULE:
Schedule changes are well communicated
COMMUNICATION:
Communication between mech and operat. is good
Communication with Chem Mix is good
Communication with warehouse for leader is good
ORGANIZATIONAL:
TWO operators changing applicators, TWO operators setting new parameters and the rest cleaning
WORK METHODOLOGY
Once job is complete, shift is done. No incentives to continue with other shifts work.
Material/tools scattered and not ready
Before Shutdown sometimes have cleaning material ready at each station
Division of labor is such that people are doing what they want and what they are good at.

Sometimes operators in headroom have to wait for clean applicator to sit on stone table for 4 hours, before being able to disassemble next applicator. Only one stone table

FIGURE 14: NB6 Gantt Chart cont.



11X - from paper to medical. Duties per shift

Operator	#	PROCESS: Changeover for 1 oven and 2 applicators — OPERATION	TIME (hr) BEFORE	AFTER	COMMENTS
C	1	Shutdown machine, plan, do paperwork	1.0		
C	2	Set new web path	1.5		
B	3	Pull modules out (2 modules)	1.0		
B	4	Remove applicator	0.3		
B	5	Clean applicator	0.7	0.0	External
B	6	Clean cart	0.2		
B	7	Install new applicator	0.3		
B	8	Set gap at back seal	0.5		Operators trained to perform this task
B	9	Pull module back, set gap and hock up lines	0.5		
	10	Wait for clean applicator to complete 4 hr on stone table	0.7	0.0	External
B	11	Remove applicator2	0.3		
B	12	Clean applicator2	0.7	0.0	External
B	13	Clean cart 2	0.2		
B	14	Install new applicator	0.3		
B	15	Set gap at back seal	0.5		Operators trained to perform this task
B	16	Pull module2 back, set gap and hock up lines	0.5		
D	17	Clean module enclosures (both)	1.0		Further division of labor
D	18	Clean rolls	2.0		
D	19	Change tape on rolls	1.5		
D	20	Verify rolls and change them where needed	1.5		
A	21	Clean towers(between modules and oven- 2 tunnels	4.0	3.0	Cleaning Kit at each station
A	22	Remove nozzles (20 nozzles, just one zone)	1.5	1.0	Bolts standardized; design improved
A	23	Install new nozzles(20 nozzles, just one zone)	1.5	1.0	Bolts standardized; design improved
A, D	24	Clean oven/drier; all zones	2.0	1.5	Illumination improved
D	25	Change shims	0.5	0.2	Better design; use pins
D	26	Install plugs	0.5	0.2	Better design; use magnets
C	27	Set new machine parameters/ recipe	2.0		
C	28	Run leader/ web alignment	2.0		
TRADES	29	Complete mechanics checklist	2.0		
TRADES	30	Complete instrumentation checklist	2.0		
CHEM.	31	Clean vessels for new solutions (3 hr/vessel and 4 vessels)	8.0		Cleaning time reduced

Assumptions
SCHEDULE:
Schedule changes are well communicated
COMMUNICATION:
Communication between mech. and operat. is good
Communication with Chem Mix is good
Communication with warehouse for leader is good
ORGANIZATIONAL:
TWO operators changing applicators, TWO operators setting new parametersand FOUR at oven and TWO with rolls
WORK METHODOLOGY

Material/tools ready
Division of labor is such that everyone is working in parallel and helping others when their task completed

NOTE:
No waiting in headroom, since applicators are left at sinks soaking.
They are not cleaned right away, but rather focus on bringing the machine up and running as soon as possible and then focus on cleaning applicators. Division of labor within shifts is eliminated.

Table 2 summarizes the current changeover practices at each site. From this summary, the reader can identify the diverse and unique practices at each site, as well as the different challenges that each one has.

	N2	W5	NB6
Duration	8-12 hr	2-4 hr	24-48 hr
% of downtime	~50%	~ 10% for coating line # 9 ~ 6% for coating line #10	Data not available
Groups involved	Operators, trades, Chemical mix area	Operators and Chemical mix area	Operators, trades, Chemical mix area
Main activities	Cleaning and module exchange	Cleaning on #9 and threading the web on #10 (not including machine design problems which account for most of the c/o duration)	Module exchange and oven preparation.
Greatest % of waiting time	During the module clean up, 75% of the c/o time, the operator is waiting	If communication with Chemical mix area not close, waiting for fluids can take up to 30 min-1 hr (up to 50% of c/o time)	Cleaning the applicator can take 4 hours if another one is sitting in the stone table (only one table that fits one applicator); 50% of the c/o time per shift.
External practices	Minimum; most of the module exchange can be done as an external activity reducing ~ 90% of the time required to complete one module exchange.	Medium; operators clean the modules as an external activity since there are enough backups. Material is sometimes ready before a changeover.	Minimum; most of the applicator cleaning can be done as an external activity reducing ~ 40%-60% of the time required to complete one module exchange.
Man-machine chart analysis	Non value added time walking, screwing parts & waiting.	On #9 20% of the c/o time is for cleaning and 27% is spent screwing parts. For #10 43% of the c/o time is screwing parts.	Non value added time walking, repeating same motions and screwing parts Oven nozzle exchange and clean up are extensive operations due to its poor design.
Gantt chart analysis	Each different group works in parallel; however important dependencies between groups. Inefficient way to maximize labor force. Schedule changes affect amount of preparation before a changeover.	Good division of labor among operators. Dependency with Chemical mix area can delay c/o significantly. # 9 reduce approx. 15% of its time by improving the cleaning procedure. #10 can reduce the wasted time looking around for tools.	Poor division of labor among operators and hence minimal parallelism. However, communication among different groups is good. Since clean up of applicators is not external, it adds dependencies to the current procedure.

TABLE 2: Summary of the current changeover practices at each site

3.2. Benchmarking

3.2.1. Internal Benchmarking:

Although the 3 sites have unique cultures, machines, and procedures, these differences provided an ideal ground for internal benchmarking. Each site could learn from the other sites' problems, interventions, and outcomes. Some practices are applicable throughout the 3 sites, yet others are too specific to be shared.

Table 3 enumerates a list of changeover best practices. They ranged from improvements in communication among work groups to specific changes in the setup process. In the following paragraphs, some of the best practices are described in more detail.

W5 has proven how valuable external activities and appropriate work distribution are for a changeover process. Cleaning applicators while the machine is running – converting an internal activity into an external one – saves 3-4 hours. If such practice were implemented at NB6, where it can be implemented, it could save more than 3 hours per shift. Another important practice identified at W5 is the use of overflow alarms for waste drums. A similar practice has already been implemented at N2 after observing operators do the same task by direct visual inspection using a flashlight. Moreover, W5 has some degree of cross training that helps to eliminate dependencies between work groups. Finally, W5 operators are now involved in the day to day decisions such as schedule changes. Empowering employees improves communication helping to run a more efficient production line.

The following are practices observed on the production floor at W5:

- Operators are trained to complete all changeover operations
- Operators work as a team
- Flow charts and procedures around machine
- Backups for applicators allowing external cleaning of applicators
- Waste drum have sensors for overflow
- Pre-planning (cleaning applicators)
- Good historical data of equipment metrics
- Excellent relationships between operators and managers

On the other hand, N2 provides important lessons on how a Kaizen event helps to implement procedural changes and how modular equipment facilitates a setup . A Kaizen event allows people from different backgrounds to share ideas on how to improve a process and provides the time and the resources to implement those ideas. N2 implemented the use of tool shadow boards during a Kaizen event reducing the time spent finding tools. A process was also implemented to ensure that tools would be returned to the board once they are used.

N2's modular equipment allows a faster changeover since equipment is simply exchanged converting several internal activities into external ones. As a consequence, changeover times could be reduced approximately 2 – 3 hours. Another time saving practice at N2, and which has already been implemented at W5, is the use of portable pumps to drain fluids. The changeover process was shortened by approximately 20 minutes and ergonomic problems corrected.

N2 and W5 could adopt the way documentation and communications are done at NB6. Each functional group follows a checklist to complete the steps of the changeover process. Everyone knows where to find the setup information and the checklists. And more important, documentation is in fact used for accountability. Another time saving practice at NB6 is the use of a narrow leader, which facilitates cleaning the machine and threading the web.

In summary, each site has important practices to share with the other sites. Such practices could represent significant reductions in the changeover time. Unfortunately, the 3 sites are independent and little communication exists among them. Chapter 4 discusses how some of these practices could be implemented throughout the coating sites.

W5	Cross-functional training Overflow alarm Cleaning of applicators as external activity Managers-operators relationship Operations closely involved with schedule
N2	Change implementation through Kaizen event Use of shadow boards Cross functional groups to gather inputs Modularity of Machine Use of portable pumps to drain fluids
NB6	Changeover documentation Use of checklists Cleaning Kit carts Thread web w/ narrow leader facilitates cleaning

TABLE 3: Coating plant's best practices/opportunities

3.2.2. External Benchmarking:

Many business processes are universal in application and extend across industries (supply chain, warehouse, advertising, etc). "Applying the benchmarking process to these generic items can provide meaningful insights, particularly when the information comes from unrelated industries. Benchmarking dissimilar industries enables you to discover innovative processes, not currently used in your particular product types, that will allow your process to become the best of breed [20]." Visits and observations were conducted at 5 different coating industries following the methodology described in Chapter 1. These companies where chosen given its accessibility to collaborate with a benchmarking study and most important, its relationship with the coating industry, yet its unique coating processes and machine.

3.2.2.1. Company A:

Unionized since 1970, it prints plastic packaging using a coating technique. The changeover process is lengthy and management views it as a burden. However, management also recognizes the importance to improve it. "Changeover time has to be reduced and its frequency to increase, because the market is driving for higher customer demands." Although improvements have been made, labor issues, retention problems and poor machine design restrict the implementation of more significant changes. Positive practices observed during the plant visit include:

- Division of labor: This practice allows groups to work synchronized limiting delays and waiting time. On the other hand, if a worker is absent, work can be disrupted and the whole changeover process delayed. Company A has reduced this risk by having backup workers, although retention is affecting this strategy.
- External activities: A designated group of workers are always in charge of setting up the rolls for the next run; enough rolls are always ready to star production again during the changeover. Such practice has reduced the changeover in 3-4 hours, even though some has to be attributed to the division of labor.
- Custom modifications to equipment: the company has introduced clamps to hold the rolls in place rather than using screws, thus eliminating a non-added-value step and simplifying the job.
- Fixed Schedules: Each station has a two-week schedule posted that informs operators what they should prepare for the next run. By doing so, some external activities are accomplished ahead of time. The company has the policy not to change a schedule

unless a customer's need cannot be met. A drawback of this practice, however, is the large inventories of finished goods.

3.2.2.2. *Company B:*

A paper base manufacturer, company B supplies some of base material for film production to Polaroid's coating plants. The changeover process is obsolete and time consuming, which help to identify Polaroid's strengths. Teamwork was the only best practice worth to mention. On the other hand, several negative practices were observed during the plant visit; therefore, Polaroid should avoid them:

- Equipment condition and design: Machines were made in 1963 and almost no upgrades have been done to them. Although applicators are exchangeable, little preparation can be done before the machine is completely shut down. Most of the changeover is manual and with significant number of non-added value steps such as numerous screws. Finally, modules are non-existent.
- Poor safety conditions: Difficult conditions such as wet floors, poor lighting, and lack of safety glasses were noted throughout the production floor.
- Poor housekeeping: During the visit, tools, parts, raw material and finished goods were found all over the production floor. Labeling and organization were almost non-existent; operators spend significant amounts of time looking for whatever they needed.
- Equipment shortage: critical parts such as backups rolls and dryers' plates do not have enough backups limiting the capacity to exchange them as an external activity.

3.2.2.3. *Company C:*

This plant produces polymer-coated textiles. Its coating line is new and designed to make fast changeovers that last less than an hour. However, the coating line was designed to work with high volumes and a couple of fluids. Observation made at this site included:

- Minimal machine versatility: The machine is dedicated for a couple of products. For example, only solvent fluids are employed and certain coating techniques are feasible. By restricting the capabilities of the machine the changeover process gets simplified and reduced, but the opportunities to meet changes in demand are slender. This is a strategy decision that needs to be made before buying a new machine. At this company, the decision was to go with high volumes for a couple of products and

achieve quick changeovers when needed, and not do business with frequent changeovers for a diverse product line. It is important to understand the business strategy and harmonize it with the proper equipment set.

- Machine automation: Compared to Polaroid's coating sites, operators do not perform any task but supervise the machine. Human error is therefore minimized, as well as waiting for an operator to complete a task.
- Improved machine design: non-added value steps are kept to a minimum by using pins and clamps and by avoiding screws and bolts. As a consequence, tools are eliminated. Accessibility, visibility and ergonomic design are better than Polaroid's equipment.

3.2.2.4. *Company D:*

This company coats paper. Changeovers at this site were efficient as a result of continuous efforts to improve them. A setup takes 1-3 hours compared to 6 hours in the past. The following are the factors that have contributed to this success:

- Machine design improvements: A strong focus has been placed on improving existing equipment to facilitate the changeover process. For instance, eliminating non-value added steps by having pop up rolls instead of rolls hold by screws. Other changes to the machines include altering the coater design to facilitate the cleaning process. This last change reduced the setup on more than 30 min per changeover. As a whole, this site is an example of what changes on machine design can do to reduce changeover time and to facilitate the work of the operators. It is a matter of having a group of mechanical engineers focused on making simple improvements to the current machine; something that is very applicable to NB6 where significant savings can be achieved by making some machine design changes (refer to 4.3 Recommendations for NB6).
  - Fluid distribution/disposition: Fluids are dispensed using drums rather than lines, which reduces the time required to flush the lines. Work for Chemical Mix area is simplified. An important consideration is, if fluid consumption is high, drums could run dry. Although for this particular site, fluid usage did not represent a concern.
  - Cross-training: Operators are cross-trained and perform several functions. They run the machine, test the material, and complete the changeovers without mechanics. Although cross-training creates flexibility and facilitates the

changeover process, a company carries the risk of having no one specialized in a specific task. For Company D, cross training has been positive and not a burden given their limited number of employees. Overall, cross training has helped to reduce the setup time by shortening waiting times.

- Empowered workforce: The organizational structure of the company allows operators to make decisions. Process engineers are few and can then concentrate on Six Sigma issues. By empowering the operators, solutions are generated on the spot avoiding delays during the changeover.

3.2.2.5. *Company E:*

This company produces patches for the pharmaceutical industry and has carried out similar improvements as Company D. Improvements have made the machine more accessible, easy and fast to clean. Changeovers last on average 2 hours. Some of Company E's best practices include:

- Machine design improvements: Although 30 years old, equipment has been kept simple and with few enclosures. As a consequence, it is easy to clean and to change from one product family to another.
- Machine modularity: Modules are interchangeable and easy to wheel in and out of the enclosures. In addition, modules are clamped down rather than screwed or bolted in. Overall two important lessons can be learned from this modularity. First, how modularity allows for a quick swap (setting up the applicators can be done as an external activity) and second, the importance of having simple systems to connect the modules back to the machine. This second point is applicable to N2 where the modules are interchangeable and allow for the swap, but whose connections to the enclosures are cumbersome and require extensive non-value-added time.

In summary, these five industries have recognized the importance for quick changeovers because of the need to satisfy customers' demands. Carrying high inventories was once a solution, but high costs no longer permits it. Changeover is then a cost-effective solution. The internal and external benchmark identified that improvements in machine design, work methodology (having more external activities), team structure, and production schedule can reduce setup time considerably. From these best practices, Polaroid can access its strengths and weaknesses and determine a changeover improvement plan that incorporates all the different elements that affect a changeover. One of Polaroid's major competitors is doing exactly that by focusing on [21]:

- Developing measurement and rewards focused on stimulating changeover reduction
- Choreographing setups in advance using an experienced team
- Performing some tasks off-line before the changeover
- Moving tasks from series to parallel

3.3. Chapter Summary

Polaroid's coating plants need to streamline, standardize and simplify the changeover process. Today is the time to be more competitive and attract those new businesses. Reducing changeover time by eliminating the waste, inefficiencies and improving the changeover procedure is possible. As this chapter showed, each site has extensive changeovers that could be improved by 15- 50%.

Moreover, the internal and external benchmark identified several practices that can reduce the changeover time significantly. Such practices include improvements in machine design, work methodology (having more external activities), team structure, and fixed production schedule.

4. Data Analysis and Recommendations

After understanding Polaroid's changeover practices and comparing them with other 5 different coating industries, a series of recommendations are presented and grouped as follows for each site:

- Machine Design: elimination of wasted motions, accessibility, safety and ergonomics
- Work Methodology: "Easy Fixes" such as shadow boards, work behaviors that affect safety and ergonomic conditions, SMED improvements such as external activities
- Skills and People Management: training, team structures, employee recognition, and leadership
- Schedule and Communication: flow of information, documentation, standardization of procedures, planning, and fixed schedules

General recommendations for manufacturing flexibility are presented at the end of the chapter.

4.1. Recommendations for N2

The cross functional team assembled during the Kaizen event (see Chapter 3.2.1) identified an action plan containing several issues that are presented in Appendix C. This matrix highlights the problems observed and the action plan to correct them. The Kaizen's cross-functional team created the matrix to facilitate the implementation of any intervention and the follow up of any incomplete recommendation. Figure 15 shows that 45% of the recommendations were implemented during the one week Kaizen event. Any incomplete recommendation was assigned to a 30-day completion list.

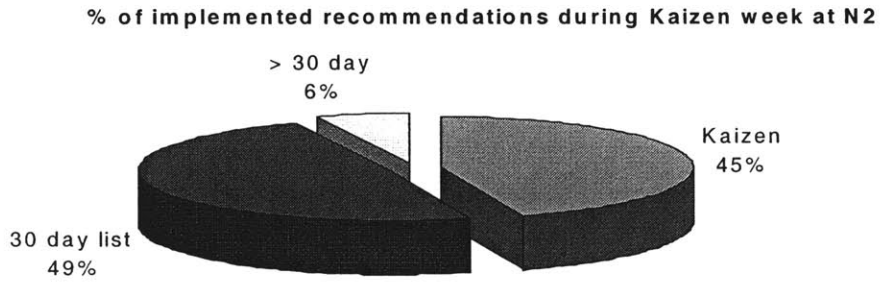


FIGURE 15: Kaizen accomplishments at N2

4.1.1. Machine Design Improvements:

Machine improvements are one of the top recommendations because poor design (such as accessibility, fixtures or wasted motions) represents about 31% of the changeover time. Some of them could be implemented with minimal capital investment. For instance, if wider fluid lines are installed, cleaning solutions would run faster thus shortening the

cleaning process by 13% or saving approximately $2000 per changeover. Making the machines more accessible is another equipment design improvement that helps with reducing the cleaning process (see Figure 16).

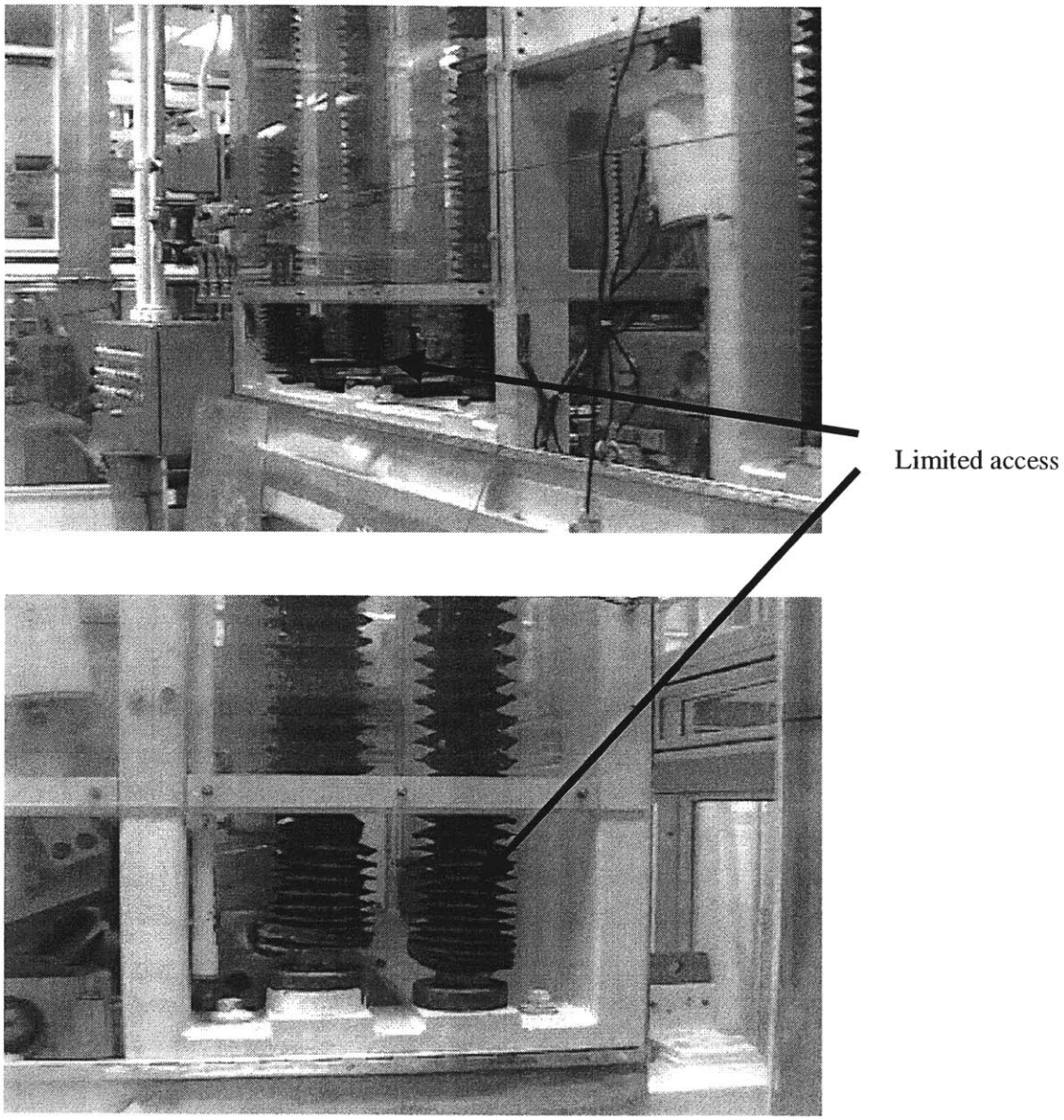


FIGURE 16: Machine Accessibility at N2

4.1.2. Work Methodology Improvements:

Work Methodology is another top recommendation because "easy fixes," for example, represents 41% of the changeover time. Most "easy fixes" were implemented during the Kaizen. An example that had also improved work satisfaction was color coding fluid lines

from the vessels to the coater (see Figure 17). That simple intervention saved approximately 5 minutes per changeover and that is without considering reduction in worker's frustration when trying to identify fluid lines. Chances for human errors were also reduced avoiding further problems during production. Another example of an "easy fix" was the tool shadow boards installed during the Kaizen event. As explained before, shadow boards eliminated non-value-added steps such as looking for tools or cleaning supplies (see Figure 18).

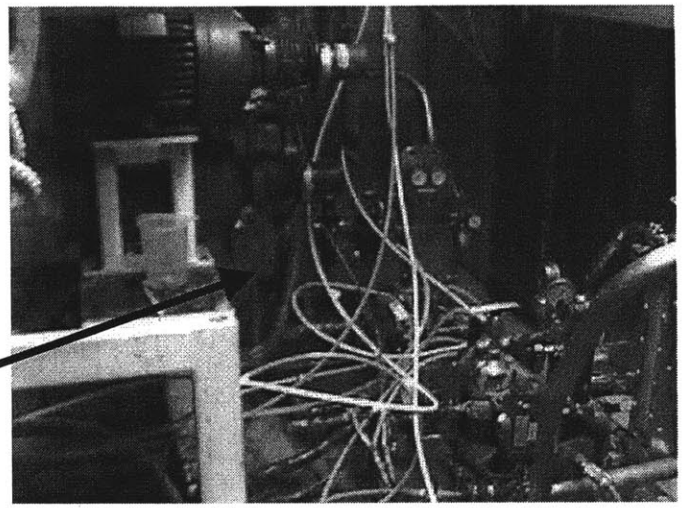


FIGURE 17: Color coding lines at N2

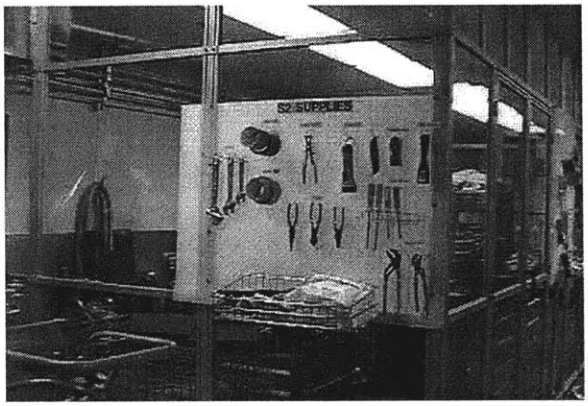


FIGURE 18: Shadow Boards at N2

Converting internal activities into external ones represents the most time saving of all the work methodology improvements. Specifically, completing the work mechanics perform to applicators before a changeover starts. N2 has enough backup modules and applicators to allow for this activity to be completed while the machine is still running. Having mechanics prepare the applicators prior to a changeover could reduce the setup time by 25-

35%. During the Kaizen event, a mock test of this new work methodology showed that changeover time could be reduced by 2 hours. As a result, N2 plans to qualify all modules and applicators to implement this work methodology.

4.1.3. Skills and People Management Improvements:

In order to implement any recommendation, a workforce has to be trained, skilled, and motivated. The Kaizen's team identified the need for a training program to improve basic skills and to level the expertise among employees. Time improvements shown on Figure 9, "Future Gantt Chart for N2," assumes a rather homogenous workforce. Currently, few operators are experts in changeover processes and those are the ones that carry most of the workload during the setup process. In addition, to increase flexibility and avoid unexpected delays from manpower shortages, cross-training has to be included as part of any training program. As mentioned before, the absence of any worker can signify delay in the changeover process if no other worker can carry out the job.

Cross-training also affects job distribution. Currently, the senior operators remain on the 1st floor and the junior ones work on the 2nd floor, where most of the "messy" work takes place (that is cleaning applicators and ovens). Such division of labor allows for minimal parallel work to occur or leaves labor-intensive areas with less manpower. If all operators have similar skills, workforce can be redistributed to areas where needed.

As mentioned above, before implementing any change, the workforce has to be motivated to learn new skills and to leave well-entrenched behaviors. One solution is to create personal (or collective) incentives and rewards when performance goals are met.

4.1.4. Schedule and Communication Improvements

Schedule and Communication improvements are as important as the rest of the recommendations. Such interventions offer a platform from which planning is carried out and external activities are completed. As demonstrated above, N2 frequently changes the production schedule and does last minute adjustments; work groups are left with no time to prepare for a changeover. Enough preparation time can reduce a setup time by more than 15%. The ability to plan schedules and to communicate action plans can be limited by uncertainty of the production process as in the case of Printcoat. In such cases, the recommendation is to fix the order of production rather than the schedules. By doing so,

workers know what product will run next and can prepare for that changeover, although the exact setup start time may be unknown.

Documentation well kept represents an important recommendation to improve communication. Checklist and logs prevents workers from varying a process. In other words, any process is standardized, thus preventing quality problems. N2 needs to update current standard procedures and documentation, which currently are not kept up to date. N2 could implement NB6's success on maintaining well-documented changeover processes.

In short, the impact of the above recommendations is shown on Figure 19's Pareto chart. Overall, if all the recommendations were implemented, setup could be reduced to as little as 4 hr. Currently, it takes minimum 8 hr to complete the changeover.

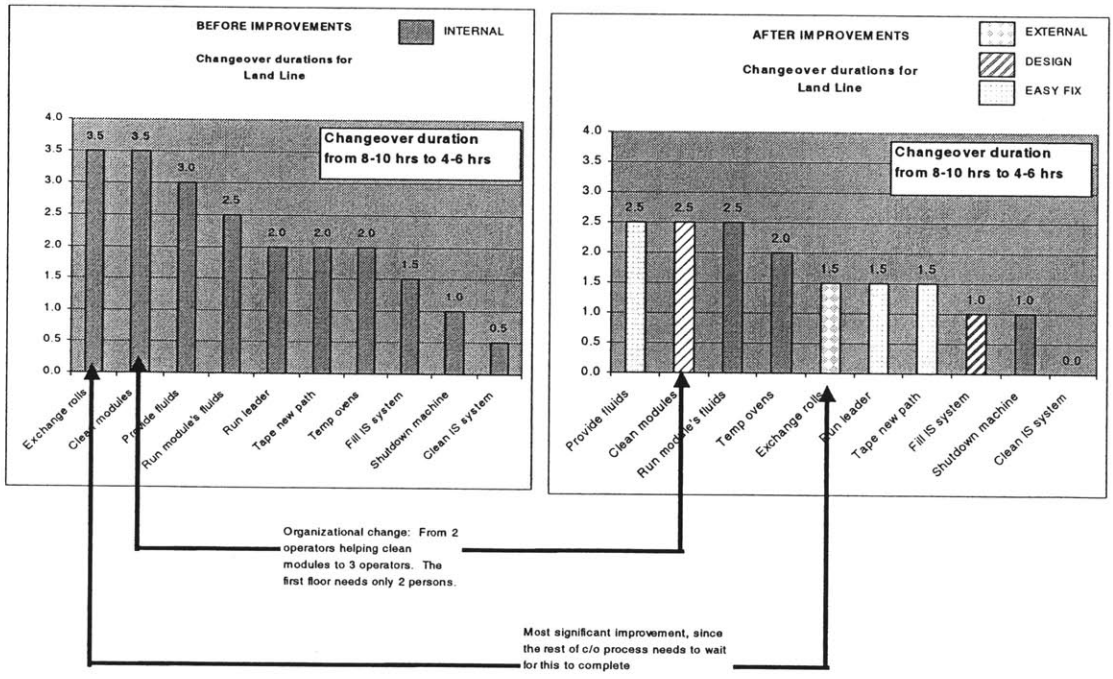


FIGURE 19: Possible changeover time reduction at N2

4.1.5. *Other Improvements*

Other particular improvements for N2 include:

- Update the Log sheets with more comprehensive downtime states. Also, to avoid any overlap in the data, several changes to the current log sheet need to be made. The changes

involve defining the down states better and adding states so that all the possible downtime states are recorded. Benchmark with W5's methodology to record downtimes.

- Empower operators for day to day decisions. Operators should have more ownership to lead improvement efforts. The Kaizen event is helping make this happen.
- Reward improvement efforts. For example, recognize the recommendations that operators make to improve working conditions, productivity, morale, etc. Although there is a recognition program for the employee of the month, it is very important to have frequent recognition and rewards for good performance. [22]
- Scheduling for changeovers become critical, once new businesses start and product families increase significantly. The schedule can minimize changeover labor and scrap by considering the modules and fluids used. A Product Requirement table (such as the one shown on Figure 20) can be the starting point to facilitate this process. With this table, the production planner can make decision on what products should run when, to minimize roll changes, flushing of fluids, temperature changes, etc. Moreover, a linear program that includes these variables and include the restrictions can help the organization optimize the schedule.

	Coating stations				
	#1	#2	#3	#4	#5
Product A					
roll					
fluids					
cleaning sln					
filters					
oven plates					
other					
Product B					
roll					
fluids					
cleaning sln					
filters					
oven plates					
other					

FIGURE 20: Product Requirements Matrix

Summary of Recommendations for N2		
Category	**Recommendation**	**Estimated time improvement***
Machine Design	Improve machine accessibility, fastening mechanisms and provide wider fluid lines	3 hr per changeover
Work Methodology	Easy fixes as color coding lines, shadow boards, having material ready. The most important change is to have the applicator exchange done as an external activity	3.5 hr per changeover
Skills and People Management	Cross training and having a homogenous skilled labor force	varies
Schedule and Communication	Allow for c/o preparation by not changing the order of products to run. Changes in schedule should be reduced. Improve communication by maintaining updated documents.	1 hr per changeover
Other	Improve moral by empowering workforce, rewarding good work and improvement initiatives.	varies
	MINIMUM TOTAL TIME REDUCED	**4 hr (45%)**

***NOTE: Improvements may be done in parallel and hence savings are not cumulative**

TABLE 4: Summary of recommendations for N2 and time reductions

4.2. Recommendations for W5

After collecting the data presented on 3.2.2 and meeting with operators to discuss possible improvements to the current practices, the following were the recommendations made to each of the coating lines. Refer to Appendix D for a summary table. None of these recommendations were implemented by the time this research was completed. However, the operations manager had a plan for implementing most of them; especially the easy fix items that improved working conditions. The implementation plan involved assigning owners to each project and determining a deadline for completion. No Kaizen event was scheduled at this site and hence some possible implementation difficulties could be possible. For instance, a changeover project could not have the priority to be completed when there are several other projects to complete. The challenge is to prioritize projects appropriately and make good use of the current resources of W5.

Overall, the following are the recommendations identified. They were categorized under the groups defined before.

4.2.1. Machine Design Improvements for W5

#9 and #10 coating lines have very similar machine design issues. Most specifically the problems are related with non-value added time screwing and unscrewing parts. For example, on both applicators the operator has to remove a pipe and metal foot (which each has 4 screws to remove) each time the applicator is changed. Refer to Figure 21 for a

picture of the pipe and foot. The only reason to do so is because the applicator box is designed to fit just the applicator, without the pipe or metal foot. By identifying this design problem, future applicator boxes can be made to fit the applicator with pipe and metal foot. This will eliminate approx. 12 min from the changeover time (which represents ~38% of #10 changeover time and ~35% of #9 changeover time).

4.2.2. Work Methodology Improvements for W5

Work methodology improvements represent most of the recommendations made. Whether they are to correct difficult working conditions or to eliminate wasted motions, these recommendations can help reduce changeover time. First are the difficult working conditions to correct. For #9 it represents eliminating the manual operation to clean the tray. Operators are working on their knees, breathing the fumes of the fluids they are draining and reaching inside the tray. See Figure 22. This should be corrected by having a portable pump that will drain all the fluids from the tray. Changing this practice will save ~15 min per changeover.

On #10, the difficult working conditions happen when the operators tape the web from #10 coater to #10A coater. Two operators have to crawl under the machine, lie on their stomachs and tape the web. Moreover, the space is tight and metal bars are on the floor. See Figure 22a. The initial recommendation was to find another place to execute this task. However, after several discussions with the operators, they assured that this is the only place to do it. If this is the case, then the recommendation is to improve the methodology and/or working conditions that are currently on place. For instance, pad the metal bars to eliminate any direct contact with them, or use a narrower web so that this job is done quicker. Second, are the easy fix recommendations, which include the shadow boards (similar to N2) and assigning a closer location to the parts exchanged during the changeover. The idea is to eliminate any non-value-added activity: walking, looking for tools, etc. Finally, is the opportunity to convert an internal activity to an external activity. This recommendation is specifically for #9 coating line (#10 is already very efficient in doing external activities). The improvement is to clean the tray while the machine is running. During the changeover, the dirty tray should be swapped for a clean one and hence 12-15 min of cleaning time are saved. The operators were very supportive of this recommendation and liked the idea of having inserts to swap during the changeover.

FIGURE 21: W5 Foot and Pipe parts

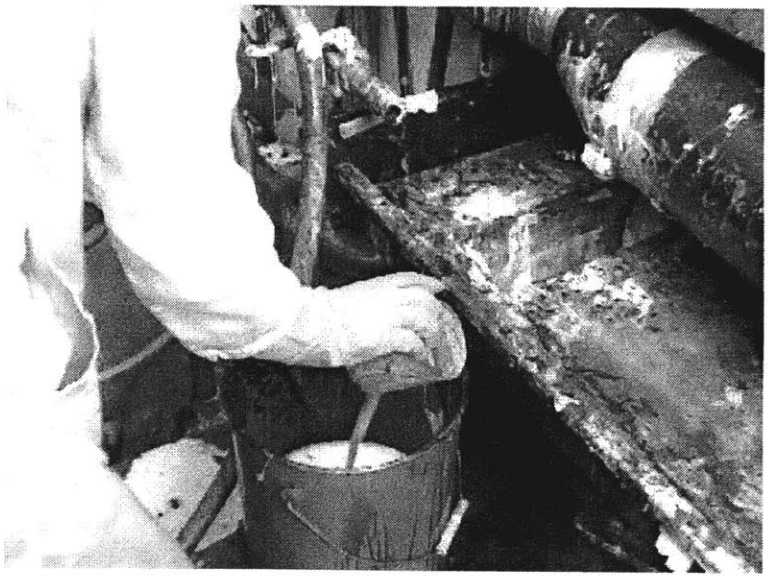


FIGURE 22: W5 cleaning procedure

FIGURE 22a: N2 working conditions to tape the web

4.2.3. Skills and People Management Improvements for W5

As mentioned before, W5 has a very experienced work force. Its operators know the coating lines very well and perform multiple tasks. Nevertheless, as new operators are trained it is beneficial to return to the old cross-training program W5 once had. Under this program operators rotated between different functional groups and coating lines. Every week a new team runs each coating line, but the lead for the coater did not rotate. He/she trained the new group. It is important to restore the diversity of skills among all the employees, since this site is running with a very slim work force.

4.2.4. Schedule and Communication Improvements for W5

Finally, Schedule and Communication improvements at W5 include two items. First, the fact that the operators are highly experienced, can be a problem when the operators are very confident of what they do and ignore documentation or checklists. These operators should be responsible for writing down the changeover procedures and defining the standardized work. Currently, W5 documents the requirements for each changeover, but very few operators read it or refer to it. They rely on their experience and verbal communication for the changeover procedures. As new products are introduced and as new operators are trained, it is critical for everyone to be informed on the changeover procedures and requirements. Operators need to be accountable for completing all the required tasks and hence, implementing a system where the checklist items are signed off as completed, might be the answer.

Moreover, it is important to revise the way the current information is documented; whether it is too complex to use, its presentation is too cumbersome or it is just not up to date. The second recommendation under this category is to improve the communication with W8 to avoid delays during the changeover. This site has the challenge to work with a separate group for the distribution of its fluids. Consequently, a very tight communication regarding changes on the schedule, changeover start time, fluid requirements, etc is very important.

As a whole, W5 has an opportunity to reduce changeover time on each of its coating lines by approx. 15%. The recommendations include easy fixes, improvement in communication, use of checklists and changing some of the work methodologies. These improvements will affect # 9 line the most, given it requires cleaning and change of applicator. Figure 23 shows setup time can be reduced by 30-40 min.

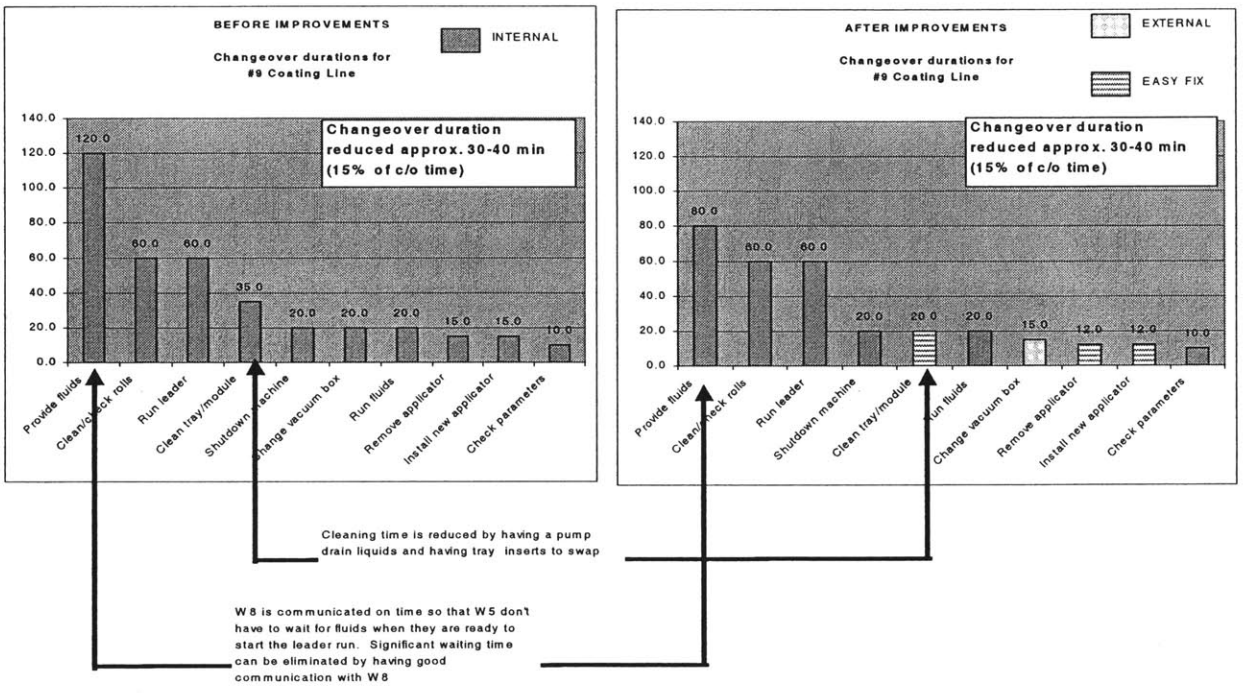


FIGURE 23: Possible time reduction at W5's #9 coating line

4.2.5. Other Improvements

Other particular improvements for W5 include:

- Document machine procedures and metrics online. Although most of the information is recorded and available for anyone, it is on hard copies and not in soft copies. Start recording information in soft copies to facilitate its distribution and access.

- Reward productivity improvements. The site is very good at verbal recognition and rewarding the hard work during campaigns. However, managers are limited in rewarding productivity improvement efforts with the $20 cards.
- Document the rules that are used to optimize the schedule. Currently, operators and the site planner have certain rules of what products to run back to back to optimize fluids and minimize changeover time. This type of information should be documented for future reference.
- Since two contract-runs were observed during this research, the following recommendations are particular for new runs. All the other improvements will affect new runs and hence will improve the response time.
    - Identify contact people to call in case of a problem during a changeover.
    - Communicate expectations. How many rolls to run? When should the campaign start and finish?
    - Identify any special requirements for this new product run. Fluids, temp, flows, speed, etc.

Summary of Recommendations for W5		
Category	**Recommendation**	**Estimated time improvement***
Machine Design	Improve machine accessibility, fastening mechanisms and eliminate removing parts just because storage box not big enough.	20 min per changeover
Work Methodology	Improve cleaning procedure for #9 and web threading procedures for #10.	25 min per changeover
Skills and People Management	Return to rotational program to allow for cross training.	varies
Schedule and Communication	Make better use of the available documentation. Maintain close communication with W8.	varies
Other	Move towards documenting machine metrics and c/o procedures online.	varies
	MINIMUM TOTAL TIME REDUCED	**35 min (15%)**

***NOTE: Improvements may be done in parallel and hence savings are not cumulative**

TABLE 5: Summary of recommendations for W5 and time reductions

4.3. Recommendations for NB6

NB6 has the most extensive changeover process and the largest equipment set. Twenty-two improvement items were identified at this site, with the potential to reduce changeover time by ~35%. The recommendations presented here have the inputs from the operators and shift supervisors. Similar to W5, there was no Kaizen event planned for this site and hence the operations manager owned the implementation of the recommendations. Most of the improvements included easy fixes and machine

design changes. As Appendix E shows, the recommendations were presented for the top procedures completed during a changeover: applicator exchange, oven/nozzles change and machine clean up.

4.3.1. Machine Design Improvements for NB6

Machine Design issues account for 38% of the improvements identified. Most of the issues are related to poor accessibility, poor ergonomic conditions or extensive use of screws and bolts. As mentioned before, correcting these machine design issues can represent extensive capital investment and not significant timesaving to justify for it. The issues were highlighted to prevent similar problems as new applicators, oven nozzles, etc are made. The few machine design issues that could be corrected with minimal capital investment and significant changeover improvement include:

- Seals are difficult to screw in and out. It is also difficult to access holes. Operators are frustrated with the poor design of this part. See Figure 24. The suggestion is to redesign the seals for a one-piece part that is hold to the applicator with pins. A mechanical engineer should work with an operator to correct this problem.

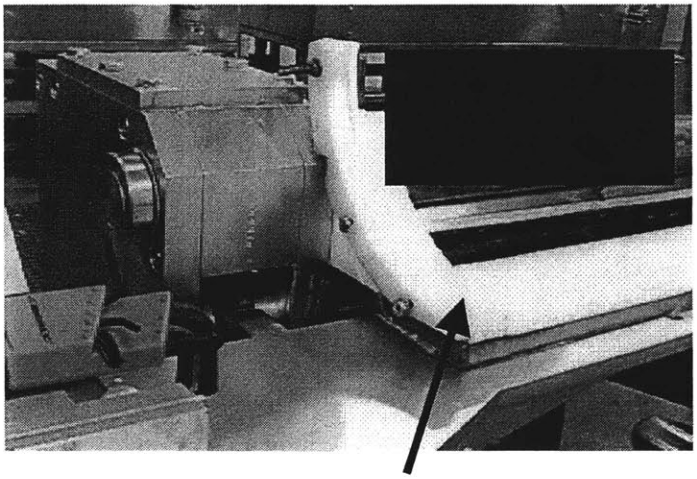


FIGURE 24: NB6 Seals and screws

- One side of the oven does not have a notch to fit the nozzle bolt, but a hole. This makes it more difficult for the operator to fit the bolt in. The solution is to have a notch at both sides of the oven. See Figure 25.
- The plugs to cover the nozzle openings require screws. It is difficult to screw the part due to its location. It will be easier if the plugs had a magnet mechanism that hold them together to the nozzle base.

- Not all the shims are held with pins. #2 oven does, but #5 has all shims hold with screws. It is difficult to reach for a screw that falls. Redesign all shims so that they are held with pins, a one step process. See Figure 26.

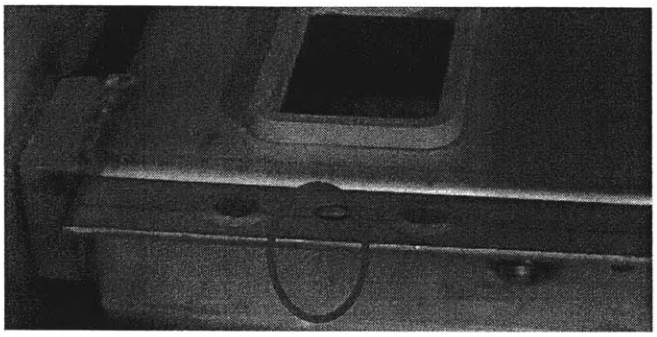


FIGURE 25: NB6 Oven notches

FIGURE 26: NB6 Oven shims

4.3.2. Work Methodology Improvements for NB6

Several work methodology improvements were identified. Easy Fix issues account for 42% of the recommendations and approx. 2 hour savings per changeover. Some examples of these improvements include: standardizing the bolts used to hold the nozzles, providing a portable lamp to help the operators clean inside the oven, create shadow boards at each coating station and define how much cleaning is required for the medical run.

On the other hand, there is one external activity that can reduce changeover time by 8-10 hours. The current procedure requires that the applicator be removed and cleaned immediately. This process involves soaking, drying and cooling the applicator on a table before storing it back on the shelf. Sometimes, the table has another applicator cooling down and a backup is created. The cleaning can be done as an external activity since most of the time a different applicator is used. There are enough backups to allow for the swap and the cleaning can be completed once the machine is running. However, to convert the cleaning operation into an external activity, certain logistic problems need to be resolved. Such as: # of sinks that will allow for the applicators to soak while the changeover is completed, distribution of labor, and backups for new products. Distribution of labor refers to a redefinition of what each shift does during a changeover. More of this is discussed on 4.33.

Finally, there were two work methodology improvements for some difficult working conditions. The first one is to have a ladder in the applicator room. This will allow the operators to reach the applicators that are stored in the top drawer safely and eliminate any shortcuts operators might use to reach. Second, provide a flat surface for the operators to rest their backs while cleaning the ovens. See Figure 27. This tool needs to be light and easy to carry so that operators have the incentive to use when needed.

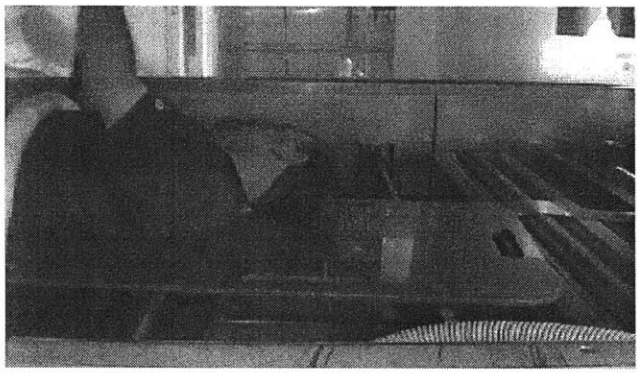


FIGURE 27: NB6 Flat surface to rest back inside oven

4.3.3. Skills and People Management Improvements for NB6

As discussed before, a redefinition of work distribution can reduce changeover time significantly. Currently, the tasks to complete a changeover are distributed evenly among the three shifts. So, for example, each shift has to exchange certain applicators, change

oven nozzles for a certain oven and clean certain parts of the whole coating line. The idea is to have a fair distribution of the work. However, when a shift finishes their tasks, there are no incentives to continue working on the tasks of another shift. This can create buffers in the current changeover process that can be eliminated by redefining the work distribution. Refer to Figure 14 for the Gantt chart that demonstrates the current and proposed division of labor. The suggestion is to eliminate the distribution of tasks among shifts and rather alternate the shift that starts a changeover. The expectation is that the shift that starts the changeover process executes as many tasks as possible given a certain order; whatever is left, can be completed by the next shift and so on. The goal to finish a changeover within 3-5shifts should be indicated by management at the beginning of each changeover.

Another important recommendation under this category is to cross-train operators. For similar reasons as discussed for N2 and W5, a cross-trained workforce offers more flexibility in the long run.

4.3.4. Schedule and Communication Improvements for NB6

As mentioned before, this site is very thorough with its documentation and use of checklists during the changeover process. A standard changeover procedure is defined for each run. NB6 is very efficient for the changeover of existing products, the challenge is to make use of these communication and documentation competencies for the new contracts. Similar to the recommendation made at W5, this site should consider the following communication elements for new contracts:

- Identify contact people to call in case of a problem during a changeover.
- Communicate expectations. How many rolls to run? When should the campaign start and finish?
- Identify what special requirements are needed for this new product run. Fluids, temp, flows, speed, etc.

Second, NB6's operators need more direction on how much cleaning is required for a medical run. Currently, everyone is aware of how important cleaning is for the medical product, yet there is no parameter or metric that helps the operators understand how much cleaning is enough. It is critical to define such a parameter because the operators are spending significant time cleaning to avoid responsibility for poor product quality. How

much cleaning is required to minimize changeover time, yet maintaining high product quality? This is the question that needs to be answered.

As a whole, NB6 can reduce changeover time by approx. 35%. The recommendations include easy fixes, machine design, improvement in work distribution and cross-training operators, and changing some of the work methodologies. Figure 28 shows setup time can be reduced to less than 2 days.

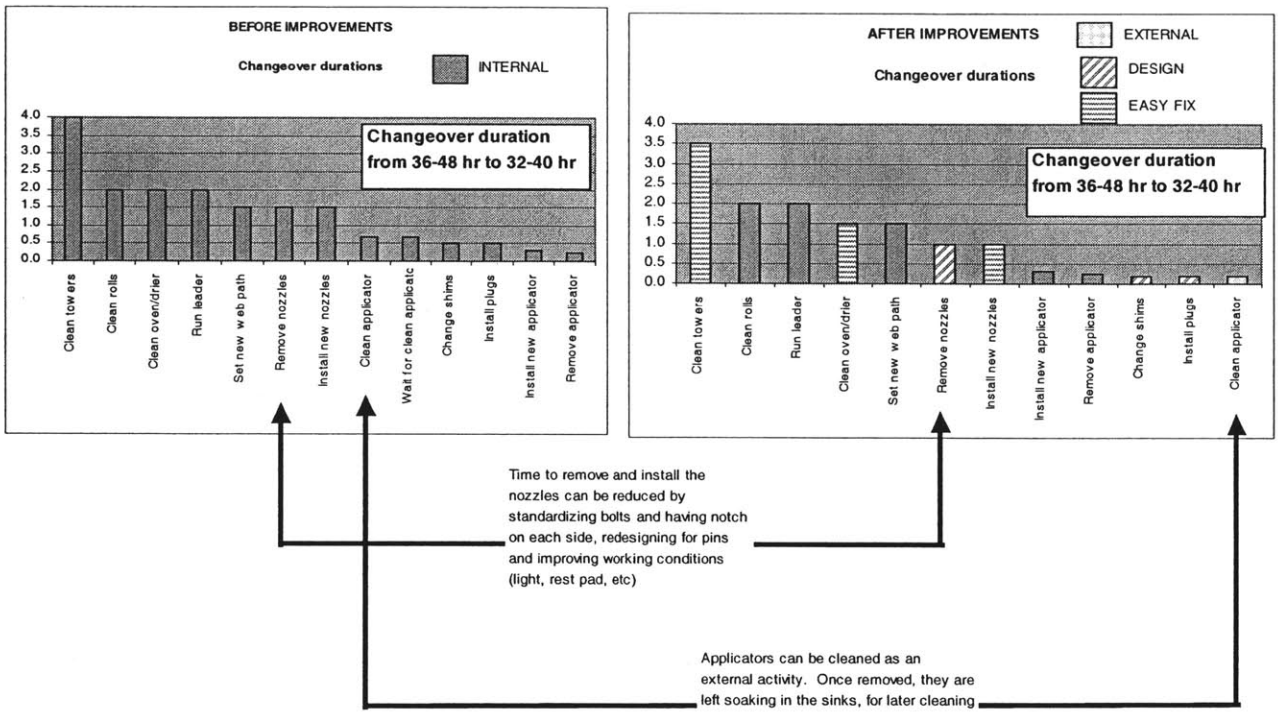


FIGURE 28: Possible time reductions for NB6 coating line

4.3.5. *Other Improvements*

Other particular improvements for NB6 include:

- Log sheets for downtime states: Document the contributors for the downtime states. This data will allow NB6 to focus its resources in resolving the top issues that represent the highest downtime percentage.
- Empower operators for day to day decisions. Operators have suggested many of the recommendations highlighted in this research, yet they are not empowered to do them and hence nothing has been done.

- Reward productivity improvements. At NB6 too, there needs to be more incentives for recommending and/or implementing improvements. Very little reward and recognition is done to motivate people to do more than what they are required. A possible idea is to institute a bonus program or certificate systems where anyone can recognize another person with a $20, $30 or $50 certificate for his/her good work. The key here is that recognition does not only come from top-down, but it can come from anyone in the organization.
- Reduce cleaning vessel time at Chemical Mix area. As changeover time for operations is reduced, Chemical Mix needs to reduce its time to clean the vessels. Several alternatives can be analyzed:
  - Invest in a second cleaning system (CIP) for aqueous and solvent
  - Review the cleaning method for each fluid and determine if it requires going through the cleaning system. Maybe some vessels do not require such a comprehensive cleaning. However, the risk of residuals, waste treatment and others need to be evaluated.
  - Modify the cleaning cycle per vessel for a shorter time. Maybe the same level of cleanliness can be achieved with 2 or fewer hours and not 3 hours.

Summary of Recommendations for NB6		
Category	**Recommendation**	**Estimated time improvement***
Machine Design	Improve machine accessibility, fastening mechanisms and reduce repetitive motions.	7 hr per changeover
Work Methodology	Easy fixes such as standardizing bolt, providing a potable lamp, and shadow boards. Most important have as an external activity cleaning the applicator.	10 hr per changeover
Skills and People Management	Redefine work distribution among shifts and within the operators of a shift. Allow for more parallel work.	4 hr per changeover
Schedule and Communication	Communicate cleaning expectations clearly.	varies
Other	Record downtime states. Focus on reducing cleaning vessel time at Chem. Mix area.	varies
	MINIMUM TOTAL TIME REDUCED	**12 hr (35%)**

***NOTE: Improvements may be done in parallel and hence savings are not cumulative**

TABLE 6: Summary of recommendations for NB6 and its time reductions

4.4. Overall Lessons Learned

After completing a thorough analysis of three of Polaroid's coating plants and after completing an external benchmark to five different companies, important lessons were learned about the issues that contribute the most to changeover downtime. Following is a description of those lessons learned.

4.4.1. Training and Expertise:

The experience and training of the operators play a large role in the duration of changeover times [23]. Cross-training operators, ensuring that the training level among employees is not too dispersed and that the teams coordinate its skills appropriately is critical. As new employees are hired it is very important too, to assure that they are making good use of the documentation and checklists. The result is more flexibility to move employees to different jobs, fewer disturbances when someone is absent and fewer burdens on the couple of employees with high training.

4.4.2. Documentation:

While the changeover process might have been documented for each run, the operators are not following it or not referencing to it during the changeover. What is required is a clear, easy to use, concise documentation for each functional group involved during the changeover. Moreover, have the operators accountable for using the checklists and information by having them sign the items as they are completed. Also, it is important to review the documentation periodically and upgrade it as changes are made. Having a standard, updated document helps to reduce errors and to follow a process that has previously been defined as the best practice.

4.4.3. Lack of Changeover Awareness:

Generally, operators are not aware of how costly it can be for Polaroid to have extensive changeovers. Since most sites are underutilized, this problem has not been too critical and hence operators have the attitude of "changeover equals break time". Nevertheless, this attitude can be very harmful in the long run when contracts start coming to each plant and capacity limitations are present. Operators and supervisors need to be better informed of why quick changeovers are important and critical for a flexible manufacturing line. It is a change in attitude and culture towards changeovers. As Spencer Johnson said in his book

Who Moved my Cheese [24]: "Change happens. Anticipate Change. Monitor Change. Adapt to Change Quickly. Change. Enjoy Change! Be ready to change quickly and enjoy it again and again."

4.4.4. Machine Design:

Although most of the coating lines analyzed were 20 years old or more, significant upgrades have been done to optimize the changeover process. The industry has already recognized that through improvements on the equipment significant timesaving on the changeover process are possible. It is inevitable that changeover operations include motions such as taking off and putting on parts; however, most changeover operations include far more of these motions than necessary. Examples of such unnecessary motions include [25]:

- Loosening, removing and then refastening bolts
- Inserting and removing nuts and washers
- Removing and inserting braces, block, cushions and spacers
- Removing and attaching chutes
- Removing and attaching air hoses
- Removing and attaching pullout conveyors

How can this wok be reduced? To begin with, instead of removing a bolt or other fastening tool, simply loosen it. The fastening strength lies only in the final turn of the bolt or nut, all the other turns are pure waste. By just loosening the bolt, it eliminates a lot of work, since it saves from having to loosen the bolt until it comes off, put the bolt down, and later find the bolt, replace it, and tighten it. Instead, just loosen a little and tighten a little. If possible, keep the bolt attached to the bolster. A better solution is to have boltless fastening design to eliminate all the waste. To do this, some ideas from the book Kaizen for Quick Changeover: Going Beyond SMED include [26]:

- Use wing nuts
- Use pear-shaped holes and U-shaped washers with hex bolts
- Use independent fastening tools (such as L clamps)
- Use hinged bolts with wing nuts
- Use U-grooves with U-shaped washers
- Minimize the variety of fastening tools: ratchet wrenches, T-head bolts, electric-powered fasteners
- Reduce the points of fastening points

- Cut down all screw threads to three turns
- Use boltless fasteners

Another important machine design fault is the limited accessibility to reach inside the machine. During a changeover, cleaning is very important and providing machine designs that allow easier accessibility can eliminate poor working and ergonomic conditions. Furthermore, a good machine design refers to the elimination of adjustments. Adjustments are made necessary by changeover settings that do not fully meet relevant standards and specifications. All too often, settings are left to the operator's discretion. Items are not set precisely according to standards, which usually becomes apparent during the test run. So adjustments must be made until the test run produces a non-defective product. None of this adjustment work adds value to the product. Some solutions for this problem include fixed standards, use only hi-low settings, use templates to eliminate judgements, etc.

4.4.5. Equipment Modularity:

After observing modular and non-modular equipment, the pros and cons for modularity were learned. The most obvious advantage of modular equipment is the increased flexibility that it can offer to a coating site. By having pullout modules with exchangeable applicators, a coating site can offer different coating techniques and hence produce multiple products. However, not all modular machines are well designed and exchanging the applicators can be tenuous and time consuming. If the design issue is corrected and the exchange of applicators can be done quickly (no bolts or screws), then the second problem to resolve is to have enough backups so the exchange is just a swap of modules. The idea is to exchange the applicators as an external activity and just swap the modules during the changeover (as discussed for N2). A final issue to resolve for modular equipment is to have a production strategy; given its modularity it is very easy to fall into the trap of producing anything for anyone. It is very important to develop a strategy that will allow for quick changeovers, low inventories of finished goods, and also low inventories of types of applicators. Choosing who the customer is and what volumes to offer is key.

On the other hand, a non-modular equipment has the advantage of offering faster changeovers since fewer parts need to be changed (such is the situation for W5). Nevertheless, it is very restrictive and limits a flexible-manufacturing environment. This is not what today's customers want to hear from Polaroid's coating plants. The ideal coating

equipment is one that has the advantages of the modular machine (flexibility), but with the fast setups of the non-modular machine. Fortunately, this condition (fast setups) can be achieved by applying the different recommendations mentioned in this study.

4.4.6. Changeover Preparation (External activity):

Although it sounds like common sense, ensuring that everything that is required for a setup is ready, organized, and on hand is critical. It is OK to move the arms, but not the legs. Eliminate the "search" waste that occurs during a changeover. Waste in [27]:

- Searching for, finding, transporting the changeover tools or parts
- Searching for bolts, nuts, washers to fasten parts
- Waiting for available crane
- Searching for inspection tools
- Searching for cleaning solutions
- Waiting for material, such as leader for test run

The list can go on and on. Changeover is full of searching, finding, selecting, waiting and arranging material that don't add value to the product. To eliminate this waste, everything needed for a changeover should be prepared and in place. Shadow boards, cleaning kits, labeling carts, etc are ideas of how to reduce this waste.

4.4.7. Management Communication:

Sharing the vision for quick changeovers and flexible manufacturing throughout the organization is not an easy task. This type of communication should come from top management and has to be reinforced constantly. The ideal situation is when there is complete consensus on the changeover goals and objectives throughout the company. Everyone has "bought into" the direction and has set aggressive but obtainable goals. All areas work together including Chemical Mix, trades, warehouse, operations, engineering and so forth. Significant changes to changeover can be done quickly through excellent coordination, motivation and cooperation. For this to happen there has to be full commitment from management and a tracking system that matches goals with performance.

4.4.8. Empower Workforce:

A significant number of the presented recommendations came directly from the people who work on the floor, those who complete hundreds of changeovers per year. If these

employees had some autonomy and were empowered to improve their work area, great productivity improvements will happen. It also shows how management trusts the operators and allows them to set the working conditions for their working area. Give ownership to those who do the work; they need to feel the urge to reduce changeover time and work towards making Polaroid a better place. Overall, it is a value to empower people to work more efficiently [28].

4.4.9. Reward and Recognition:

Recognition other than money and parties is important. They include V-days, family day, company souvenirs, etc[29]. But if money and parties is all that can be offered, it should be a starting point to recognize the good work and stimulate more of it. Also, implementing a system where anyone can recognize and reward the good work of another person is critical; recognition should not always come from top-down. As a whole, any company should be conscious of what really motivates its operators to keep performing beyond expectations and reward accordingly.

4.4.10. Workforce structure:

Regardless of who is involved during a changeover and what is the division of labor among those members, the most important idea is good teamwork. Teamwork is an integral and very important part for a successful changeover. People should be satisfied with their involvement and participation in the changeover team. To stimulate this type of behavior, there should be team recognition and reward for camaraderie and collaboration within the members of the team.

Nevertheless, workforce structure plays a significant role in the changeover process too. Several structures were observed throughout this research. From the total division of labor in a union shop (one employee for fluids, one to clean rolls, one to exchange the rolls, etc), to the totally cross-trained team (each individual was trained to do all the tasks, even those from different functional groups such as mechanic). Again, each structure has its pros and cons. The division of labor creates experts in one area. However, a very close communication and coordination of events need to happen to guarantee that a changeover is done without waiting periods. Any miscommunication can cause delays and frustrations. On the other hand, the perfectly cross-trained team does not offer any expertise, but rather someone who can do the essential tasks. The advantage is that the individual can perform

all the tasks; he/she does not have to coordinate and rely on other individuals to complete some tasks. But when a difficult situation comes, the expert needs to be called to resolve the problem. In this case, the expert might not have the time to attend the problem right away and hence the changeover is delayed. Overall, the division of labor structure is good for those companies with enough resources to dedicate to certain tasks and with a very good communication system. Consequently, for Polaroid, this type of structure is not optimal since the workforce is limited at each site. The cross-trained structure best suits Polaroid given the number of employees and most important, the high experience in its workforce.

4.4.11. Changeover Metric:

As each organization has the goal to reduce changeover time, it is important to measure it and track it. The results should be posted and/or shared with those that are involved during a changeover. The immediate feedback will help focus the group on improving and working together towards a common goal. As the metrics are met, then the workforce should be rewarded for it and the standard raised to the next level.

4.4.12. Internal Benchmarking:

A lot can be learned by sharing practices across sites. Having a mechanism where peers across sites meet or have a conference call once a week can do this. At this time, they discuss problems, resolutions, approaches, etc. There is a lot that can be learned from others and hence it will eliminate the idea of "reinventing the wheel"[30].

4.5. Chapter Summary

The changeover process comprehends of multiple steps and involves different groups. This complex system of procedures and activities are unique at each of Polaroid's coating plants. The study was able to identify improvements throughout these changeover processes and to those activities that were closely related to the successful completion of a changeover. Moreover, some activities that were not as directly related to the changeover, as communication, recognition, work distribution, and empowerment were analyzed. As a whole, a holistic analysis was completed to the changeover practices at each site, which resulted in potential changeover reductions of approx. 45% at N2, 15% at W5 and 35% at NB6.

5. Continuous Improvement

The dynamics of a changeover process are often more complicated than what they appear to be. Different functional groups come into play, different expertise levels are needed, different work methodologies and structures are essential for faster changeovers and the list can go on and on. Changeover can be interpreted as a complex, large, integrated system; it is much more than executing several tasks to change from one product family to another. Changeover is a process with multiple players and multiple techniques. The best way to approach the question how to reduce changeover time is to observe the process as a complex system with multiple interactions and dependencies. That was the intent of this research; to analyze the training issues and the machine design problems, to understand the role of management as well as Chemical Mix, to observe the changeover process beyond the tasks that happened during the 4 or 16 hours of changeover. However, in this process there is always room for improvement. The following section is a critique on how to improve the methodology used so that future studies can learn from these lessons

5.1. Methodology Critique

The methodology used proved to be very efficient since the changeover procedure could be reduced significantly at each site. Interviewing employees, video taping the changeovers and working in cross-functional teams to develop the recommendations was very helpful to the overall analysis. However, the methodology focused in operations and quickly looked at other parts of the system, like Chemical Mix, warehouse, slitting room, etc. These areas affect the overall changeover duration in a minor scale than operations, but it is important to look at them too. These areas should be studied as a second phase of this project, specifically, changeovers at Chemical Mix.

A second improvement to the methodology used is to create a workgroup that analyzes the market conditions. This research assumed customers' need for quick turnovers as a static variable. It is valuable to access if this need changes over time and to what level the customer is expecting a fast response from the coating line. It will help the coating plants identify to what degree they want to focus resources on reducing changeover time to respond to customer needs or if it is purely a need to have more capacity and lower inventories. Each plant has to respond to the question why are we reducing changeover time? Is it to be more competitive? Because customers are requesting a faster response and we are lacking behind?

Or it is to free up capacity and allow for more new businesses? Or we want to reduce costs and fast changeovers reduce finished goods inventories? Or maybe is a combination of all of these options, which was the approach of this research. Nevertheless, having a closer understanding of the market can further help each plant understand its customers' needs.

Finally, this methodology used trans-industry benchmarking to access the changeover practices in different industries. It was very beneficial to observe other changeovers and learn from diverse industries' best practices. Nevertheless, it will be important too, to have an external benchmark that focuses on the competition. The ideal situation will be to have a partnership with a competitor(s) to analyze best practices for changeovers. Similar to what the high-tech industry has done by forming SEMATECH to share best practices across the industry.

5.2. Future steps

5.2.1. Chemical Mix and Finishing

As the changeover process is simplified for the Operations and Trades group, it is important to shift the improvement efforts to other areas. One of these areas is Chemical Mix. In particular, study the most optimal schedule to optimize vessel cleanup, fluid aging, and fluid disposition. Moreover, determine best practices for cleaning vessels and preparing fluids. Answer questions like: Is it necessary for NB6's Chemical Mix area to spend 3 hours cleaning each vessel? Can this time be reduced?

On the other hand, Finishing is an area that requires attention once changeovers are done frequently and production is flexible. At this point, Finishing needs to be flexible too. Currently, the area runs in batches, slitting machines are unreliable and changeovers are not efficient. The same analysis that this study proposed for the coating lines should be completed to the Finishing area.

5.2.2. Flexible Manufacturing Model

"There is an increasing recognition that agile manufacturing is a necessary condition for competitiveness [31]." The flexible plant will be able to respond to customer orders quickly, provide a broad product range, or introduce new products to the range effortlessly [32]. However, there is no company that is truly flexible in the sense of having acquired all the essential characteristics identified by the literature.

A Flexible-manufacturing model was developed to help plant managers assess themselves on where they are in the journey towards flexibility. The purpose of the model is first to grade the flexibility of each plant and second, to develop a working plan that focuses on those items that need to be mastered first. For instance, developing the vision for Flexible-manufacturing needs to be completed prior to investing resources in Benchmarking. Refer to Figure 29 for an example of the model.

The flexibility of manufacturing processes will become a critical measure for sites. This model will serve as a metric that each plant can use to periodically access its improvements towards Flexible-manufacturing.

FIGURE 29: Flexible-manufacturing Model

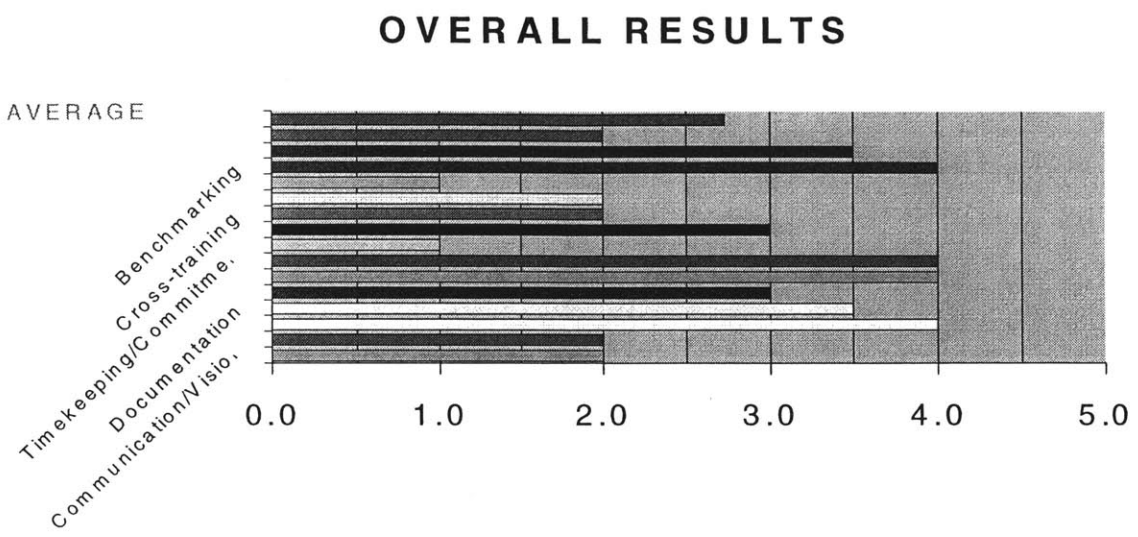
Table of Contents:

Striving for Quick Changeovers				
1. FUNDAMENTALS	**2. CHEAPER**	**3. BETTER**	**4. FASTER**	**5. FLEXIBLE**
1.1 Communication/ Vision	**2.1 Use of Resources**	**3.1 Empower Workforce**	**4.1 Machine Design**	**5.1 Ability to Change**
1.2 Teamwork	**2.2 Production Schedule**	**3.2 Reward & Recognition**	**4.2 Cross-training**	**5.2 Benchmarking**
1.3 Safety/ Housekeeping	**2.3 Timekeeping/ Commitment**	**3.3 Planning**	**4.3 Supplier Relationship**	**5.3 System Integration**
1.4Documentation	**2.4 Inventory Levels**			**5.4 Performance Measurements**

Assessment for one Category:

2.1	Use of Resources			
GRADE ONE	**GRADE TWO**	**GRADE THREE**	**GRADE FOUR**	**GRADE FIVE**
Changeover costs are not monitored each month by standard cost and variance analysis. There are no coordinated programs to fully utilize the existing resources (labor, materials, etc). Some resources are scarce and there is no good communication to optimize the existing ones.	Everyone is aware of changeover costs (overtime, scrap, overhead). Reports are created to monitor these costs and some efforts are in place to help reduce them. Nevertheless, still not a good use of the existing resources due to poor communication, lack of flexibility in the system and not enough cooperation. For example, labor is not cross-trained to reduce overtime needs. Work methodologies are poor and most changeover tasks are done in sequence and not in parallel to minimize time/resources.	Improvement teams have formed across shifts to reduce changeover costs and hence maximize the use of resources. Schedules are in place to optimize the consumption of fluids, material and availability of labor during a changeover. Some cross-functional training has initiated.	Changeover cost policy is well established and successful. A plan is put in place to identify the additional resources required for New Business contracts. The labor force has been optimized by improving work methodologies and executing more parallel operations.	Labor, material and equipment are fully utilized. Material is ready when needed for a changeover, leader runs are standard and concise. Labor is flexible and understand the changeover responsibilities. The equipment downtime is minimal. Overall, the changeover cost is reduced to its minimum as the resources are fully utilized.
1.0	1.5 2.0	2.5 3.0	3.5 4.0	4.5 5.0
				YOUR SCORE: 3.0

Results after all Categories Assessed:



5.3. Conclusions

The new strategy of emphasizing responsiveness demanded a new way of working in Polaroid's Coating plants. It required faster product changeovers and nimble decision making. When this study analyzed how the three plants were operating, the conclusion was: The plants are slow in switching from one product to another and in changing schedules to accommodate new business requirements. The plants were incapable of quick changeovers; changeovers had not improved, because improving them had not been a high priority. Managers had been judged primarily on the success in maximizing the plant's capacity utilization and product yields; the focus has been on long production runs to achieve their performance goals. The long runs meant that operators did not have to learn how to improve changeovers. They also produced a culture that placed very little value on the need for quick changeovers [33].

This study has presented alternatives for Polaroid's Coating plants to adopt quick changeovers. The type of workforce, equipment, work structure and communication has been identified for each plant. Moreover, an assessment model has been offered to help plant managers measure the improvements towards the goal of Flexible-manufacturing. Along with creating new metrics to access the plant's flexibility, each plant needs to develop reward and recognition programs that provide incentives to continue in this journey.

"Increasing flexibility may be costly in the short run but it gets easier over time [34]." It is important to emphasize the importance of flexibility, follow an action plan and incorporate change into the day to day work. However, the most important factor is giving people the support they need to achieve the change. People count more than machines and without their support, very little can be achieved.

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APPENDIX

APPENDIX A

PROS AND CONS OF LARGE LOT PRODUCTION from A Revolution in Manufacturing: The SMED System [35]

Pros:
- Since the ratio of setup time to main operation is lower, apparent operating man-hours are reduced.
- Combining setup operation reduces the number of setups, increases the work rate, and increases productivity proportionately.
- The existence of inventory facilitates load leveling.
- Inventory serves as a cushion, alleviating problems when defects show up or machinery breaks down.
- Inventories can be used to fill rush orders.

Cons:
- Capital turnover rates fall, increasing interest burdens.
- Inventory itself does not produce added value, so the tremendous physical space it occupies is entirely wasted.
- Inventory storage necessitates the installation of racks, pallets, and so forth, all of which increase costs. When inventories grow too large, special rack rooms or the like are installed and automated stock entry and retrieval becomes possible. Some companies pride themselves in automated inventory control, boasting that any item can be retrieved in three minutes or so. This in turn requires managerial man-hours for taking inventory. Although all of this has been called "rationalization", in reality it is the rationalization of waste rather than its elimination.
- The transportation and storage of stock requires handling man-hours.
- Large lots entail longer lead times. As a result, discrepancies arise with respect to projected demand. This leads to internal inventories and discarded parts. Furthermore, long lead times can mean that new orders are delayed and deadlines missed.
- Stocks must be disposed of whenever model changes take place, product becomes obsolete or it gets damaged. It can be disposed by either selling them at a discount or by discarding them.
- Inventory quality deteriorates over time. As stocks become dated, their value diminishes.

APPENDIX B

CHANGEOVER SURVEY DATE: _____

1. GENERAL INFORMATION
1.1. COMPANY NAME: _____
Address (main office):_____
_____
Telephone number: _____ Fax number: _____

1.2. PRINCIPAL PRODUCTS:
_____
_____

2. LABOR
2.1. TOTAL NUMBER OF EMPLOYEES: Hourly: _____ Salary: _____
# of shifts: _____
# of hourly employees per shift: _____
# of salary employees per shift: _____

2.2. How are the operators measured? Work completed, quality, safety, etc.

2.3. Any shortage of labor? _____

2.4. Any problems with labor retention? _____

2.5. Any problems with labor morale? Why? _____
_____

2.6. How much decision making power do the operators have? _____

2.7. LABOR UNION AFFILIATION: Yes: _____ No: _____
If so what union(s): _____
Strike history: _____

2.8. TRAINING:
Are operators cross-trained to perform different tasks in a same shift? Give an example.

How is a new operator trained?
Peer-to-peer: ____ Outside classes: ____ No training: ____ Other: ___
2.9. How is the technical expertise (high, low, medium)? Why?

3. PRODUCTION
3.1. Production Manager reports to: _____ How is he/she measured?

3.2. What is the average equipment utilization? _____

3.3. What is the finished goods inventory turns? _____

3.4. What is the average time from when you receive an order to when it is shipped?
_____

3.5. Is the weekly production schedule fixed or very variable? Why?

3.6. How are your fluids dispensed? How is the communication with production?

3.7. Are there any productivity improvement programs? Such as 6 Sigma, Lean Manufacturing, Kaizen, JIT, Preventive Maintenance, etc.

4. EQUIPMENT
4.1. # of systems (coaters) :_____

4.2. What is the age of the equipment? _____

4.3. How many coaters and driers per system? _____

4.4. COATING CAPABILITIES:
Coating techniques for each coater:

Type of fluids for each coater (aqueous, solvents):

Coater speed and width:

4.5. MODULES:
What is the flexibility of the modules at each coater? Roll exchange?

How are the rolls attached to the modules? Screws, pins, etc

How are the modules attached to the coater?

4.6. How many product families do you run per coater? _____

5. CHANGEOVER
5.1. How many times per week do you change from one product family to another?
_____

5.2. How long does it take to complete a changeover? Changeover is the time from the last good roll of product A to the first roll of product B.

5.3. What do you think of having more changeovers per week? What restricts you from performing more changeovers?

5.4. Who is involved in the changeover and what are their responsibilities?

5.5. When are changeovers scheduled? Is there a preferred shift? Why?

5.6. How do you ensure proper quality after a changeover?

5.7. Describe the steps that need to occur for a complete changeover:

APPENDIX C

N2 RECOMMENDATION MATRIX

Category	Issue	Recommendation
Work Methodology	Use of **manual fork lift** to remove and transport modules	Protect pneumatic fork lift so it does not get in contact w/ wet floor Have a bigger tray on A4 to prevent wet floor Get a different fork lift; lighter and ergonomic
Work Methodology	**A1 cart** with tubes are in the way of the operators. Floor becomes slippery	Eliminate cart and mount in on wall; no need for cart
Work Methodology	**Pull leader** out of rack very difficult due to position	Redesign for rollers Find roller/wheel racks that existed before Avoid use of bottom rack
Work Methodology	**Clean IS** in very narrow spaces	Redesign; provide feedback to Mark's project
Work Methodology	**Knobs/valves** to turn on/off fluids are too high; need to reach	Redesign and move lower Get rid of lines that are not used; organize lines better
Work Methodology	**Web drawings not updated**	Provide time to update drawings Train several operators to perform this task
Work Methodology	**Leader/base not ready**	Pre-plan; incorporate in prep procedure Improve communication with warehouse
Work Methodology	Operators **looking for tools**; walking back and forth to tool box	Provide individual tool boxes (small, portable) Wall board tools at each station Tool cart with all tools; need owner who maintains it
Work Methodology	Not enough **disposing lines** for new products	Dedicate lines for each system Provide line storage area that is assigned to an indiv. to be responsible for
Work Methodology	Looking for **straps** to lift	Not an issue, no fix needed

	rolls; only one pair of straps	Have additional straps at tool box Have straps on each roll, ready to be lifted (pre-work done ahead of time)
Work Methodology	Operators at A1 **wait for mechanic** to remove module to complete cleaning	Train one operator for each shift to serve as backup Improve communication with mechanics; call 15 min before finishing cleaning Discipline for operator to do other tasks while mechanic comes
Work Methodology	**Scrap trays**	Have backups for swap Throw away trays/inserts Have a drain Cover with Aluminum for quick cleaning Improve design of coater for no drainage
Work Methodology	**Connection to pipes** very hard to detach...broken	Clean them when detached/attached Replace after a period of time and replace broken ones (PM) Have spare parts available
Work Methodology	Difficult to find the right **web drawings**; disorganized drawer	Have drawings available on line Have wall drawing Organize drawer with a file system to find drawings and assign an owner
Work Methodology	Walking around, looking for **gloves**	Provide glove rack (storage) at those locations where needed often; Identify supply manager at each shift; replenish before c/o
Work Methodology	Operators **looking for buckets;** walking back and forth to waste drums	Have empty drums ready before c/o Have mid drum stations Have central location for white buckets and keep supplied excess Equip floor with direct drains
Work Methodology	Roll racks: **No labeling.**	Not an issue, no fix needed Enlarge engraving Post inventory status and location

		Print labels as roll stored
Work Methodology	Lines are not **labeled** or color coded	Label lines Color code all lines. Ex Hotwater Circ at A4 Have separate lines for each product Call Bruno
External	**Roll exchange is internal,** should be converted to external; there are enough backup rolls for this to happen.	Need more modules for swap Need more rolls for swap Pre-planning for systems not in used Use 4 new modules. Qualify them and have plan for total replacement
External	**Clean IS: it** can be cleaned while machine is running for printcoat	Pre-plan Provide resources
Design	Pump not able to **drain all sln out.**	More pumps Redesign drain to bottom
Design	Use of 4 **screws**	to attach rolls to module***
Design	**YO Vessels at A4 are to big** to be removed without banging equipment and walls	Dispense directly from Chem Mix Redesign vessel with same capacity, but different shape
Design	**Adjust blade** on A1	Redesign so no adjustment needed; fix setting Standard setting
Design	**Exchange blade** on A1 requires unscrew 6 bolts	Reduce # of screws One unit with blade Apply Waltham design: pins

APPENDIX D
W5 RECOMMENDATION MATRIX

#9 COATING LINE

Category	Issue	Recommendation
Work Methodology -	Reaching and bending to drain manually all solution from tray	Get a portable pump. Create extension to existing pump.
Work Methodology - Easy Fix	Tools are all over. They are close to where work is happening, but are not well organized	Shadow board for tools and any material that is frequently used at the applicator.
Work Methodology - Easy Fix	Operators are constantly looking for gauges, screws or other parts that are removed to change the applicator or vacuum box.	Provide a box to put all parts as they complete the changeover. Also have backups handy in case a part gets lost.
Work Methodology - Easy Fix	Walk to get new vacuum box	Have cleaned vacuum box at same location as applicator to eliminate some walking
Work Methodology - External	Cleaning tray is time consuming and messy	Get inserts for the trays; if inserts need to be cleaned have enough backups to clean them off line.
Machine Design	Applicator foot and pipe are attached to applicator because storage box does not allows for it to fit	Redesign storage box to allow for foot and pipes to fit. Redesign so that screws are not needed.
Machine Design	Screws to hold applicator (2 at each side)	Redesign
Machine Design	vacuum box is too heavy	Redesign for a lighter one and hence only one person is needed

#10 COATING LINE

Category	Issue	Recommendation
Work Methodology -	Taping the web is done under the coater, where there is very little space and operators have to work on the floor.	If there is no other place to perform this task investigate ways to improve methodology. For example, can a narrow leader be taped instead of a taping the whole width of the roll?
Work Methodology - Easy Fix	Tools are all over. They are close to where work is happening, but are not well organized	Shadow board for tools and any material that is frequently used at the applicator.
Work Methodology - Easy Fix	Screws to hold crane attachment	Use same concept as #9
Machine Design	Applicator foot and pipe should be attached to applicator if storage allows for it.	Redesign storage box to allow for foot and pipes to fit
Machine Design	Screws to hold applicator (2 at each side)	Redesign

Category	Issue	Recommendation
Communication	wait for W8 to provide fluids	Pre-plan so that W8 has time to supply fluids when needed
Training	Not enough cross-trained operators	Institute cross-operational training as it was done a couple of years ago
Training	Checklist and documentation available but not being used properly	Need to revise why documentation not being used. Is it too long, too complex, or is it just that there are no expectations to use them. Can a system be implemented where items are signed off as they are completed?

APPENDIX E

NB6 RECOMMENDATION MATRIX

APPLICATOR		
Category	**Issue**	**Recommendation**
Work Methodology -	Inserting crane screws to top drawer applicators, Is difficult to reach	Eliminate use of top drawer or provide ladder
Work Methodology - Easy Fix	Need to remember to carry tape, wrench, screwdriver and back pipes when moving the module back to the machine.	Have materials at each station. Create shadow boards.
Work Methodology - External	Applicator is removed and cleaned immediately. The cleaning can be done once the machine is running, since there are enough backups.	Soak the applicator in the sinks while the changeover is completed; might need for more sinks. This will also eliminate need to wait for 4 hours while applicator sits on table.
Machine Design	Screws to hold back pipe into applicator (4 screws)	Redesign
Machine Design	Screws to hold 2 sides of applicator (24 screws)	Redesign
Machine Design	Bolt to facilitate crane lift of applicator	Have bolts ready/ installed at the applicators that are sitting on the shelf ready to be used.
Machine Design	Difficult to screw side seals. Requires screws and it is difficult to access holes	Redesign seals
Skills	Wait for Mech to calibrate gap.	Cross-train employees
Skills-People management	Division of labor among shifts have caused some buffer time into the system	Eliminate division of tasks

CLEANING PROCESS		
Category	**Issue**	**Recommendation**
Work Methodology	Some of the locations where operators have to reach to clean rolls is very high and not safe.	Review locations that need to be cleaned and determine a safe method to reach them.
Communication	How much cleaning is required? No parameter is defined to help operators determine when to stop cleaning.	Define how much cleaning is needed. Document this and communicate to all shifts.
Work Methodology External	Looking for cleaning solution, wipes, etc.	Have a portable station with cleaning material that is ready

OVEN		
Category	**Issue**	**Recommendation**
Work Methodology -	Operators have to lay on their back to clean the top nozzles. There are some back supports, but not enough for all operators	Have back supports to facilitate the cleaning
Work Methodology - Easy Fix	Bolts for the nozzles are not standardized. Operators have to sort through a bucket of screws and bolts to find the ones they can use	Standardize all bolts
Work Methodology - Easy Fix	Nozzles are stored in a cart with no specific labeling or easy way to access them. Some carts have shelves that make it easier to reach to the bottom nozzle	Redesign cart that stores nozzles and assign a sorting method to facilitate identification and location for a nozzle.
Work Methodology - Easy Fix	Illumination inside oven is poor. IT makes cleaning more difficult as the operators need to hold a flashlight with one hand	Provide lamps.
Work Methodology - Easy Fix	Not clear if nozzles need to go in a special order. Operators follow an order thinking is the right thing to do, but do they need it?	Review procedure for nozzle installation
Work Methodology - Easy Fix	Need to cannibalize for parts.	Have enough back up of parts to avoid cannibalization. Have parts ready
Machine Design	The bolts are positioned on the bottom of the nozzles, making it very difficult to install or remove.	Redesign
Machine Design	One side of the oven does not have a notch to fit the nozzle bolt, but a hole. This makes it more difficult for the operator to fit the bolt in.	Have notch at both sides of the oven
Machine Design	Plugs for nozzle openings, require screws.	Redesign for a one motion application
Machine Design	Not all the shims are hold with pins. #2 oven does, but #5 has all shims hold with screws. It is difficult to reach for a screw that falls.	Redesign as the other ovens...with pins